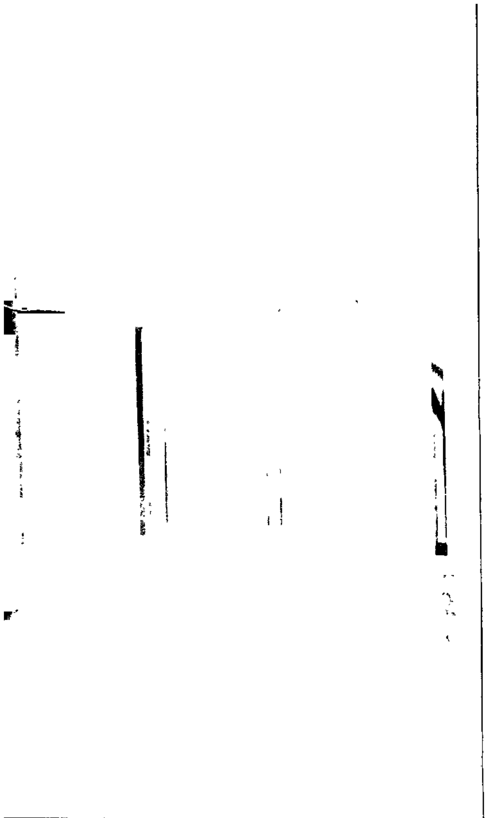

Interior of covered pure-water reservoir at Washington, D. C., before being filled with water It is covered for the purpose of keeping the filtered water clean.

Frontispiece

CLEAN WATER

AND

HOW TO GET IT

BY

ALLEN HAZEN

MEMBER OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS, THE BOSTON SOCIETY OF CIVIL ENGINEERS, THE AMERICAN WATER WORKS ASSOCIATION, THE NEW ENGLAND WATER WORKS ASSOCIATION, THE AMERICAN PUBLIC HEALTH ASSOCIATION, THE SOCIETY OF ARTS, ETC.

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TO

THE BRISBANE BOARD OF WATERWORKS

IN WHOSE SERVICE WAS MADE
THE VOYAGE ON WHICH THESE PAGES
WERE WRITTEN

PREFACE.

THIS little volume, originally written in the spare hours of a long ocean voyage, deals with the means now used by American cities to secure clean water.

Some closely allied subjects are also touched upon, including some matters of general policy, pressure, fire service, the sale of water, and the financial management of water works. This is because an understanding of these matters is often necessary to enable the means of securing a new supply, or improving an old one, to be fully considered.

Matter descriptive of existing works and their management is frequently used where principles can best be shown by it; but it is the object to illustrate principles and not to describe the works that are mentioned.

Its object is to help beginners to understand something of the first principles.

In the present edition chapters have been added upon the red-water trouble and upon the disinfection of water supplies, in the knowledge of which great advance has been made since the first edition.

The statistics have also been brought up to the census of 1910, and corrections and additions made throughout the volume.

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CHAPTER I.

IMPOUNDING RESERVOIR SUPPLIES.

Croton Works of the City of New York. In the year 1842, when New York City had a population of about 355,000, Croton water was first brought to the city. It had taken seven years to build the works. The water was taken from the Croton River through an aqueduct 41 miles long to the city. This aqueduct was 8 feet 5½ inches high, 7 feet 5 inches wide, had a slope of 12.6 inches per mile, and was capable of carrying 95,000,000 gallons of water per day. This aqueduct crossed the Harlem River which separates Manhattan Island on which the city stands from the mainland on a masonry arched bridge, called High Bridge, which to-day, sixty-five years afterward, is one of the most notable of the engineering works of the metropolis.

In the city were built reservoirs to receive and hold the water, and from them it was piped through the streets.

Afterwards, in 1890, a much larger aqueduct was put in service, capable of bringing 300,000,000 gallons of water per day from the Croton River.

A dam was built across the Croton River at the point

of intake, raising the water some 40 feet, or 26 feet above the top of the aqueduct. The use of this dam was principally to raise the water to the required elevation; but it also served to a slight extent to hold back and store water when an excess was flowing in the river and make it available when there would not otherwise have been enough.

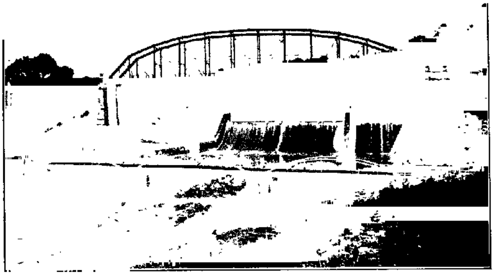
When the Croton works were built the city used 12,000,000 gallons of water per day, and the natural flow of the river was sufficient. The Croton River is a relatively small stream. Above the intake it drains an area of 360 square miles. This is equal to a square with sides of 19 miles each.

The area from which water is taken to supply a city is called in England a catchment area, and commonly in the United States a watershed. The English term is more accurate and better.

In dry weather the flow of the Croton River was not very large, and as the city grew and needed more water it soon happened that there were times when there was not enough.

The city then began to build storage or impounding reservoirs. Dams were built across various tributaries of the Croton River, forming artificial lakes behind them. The larger of these dams were of solid masonry. The smaller ones were often built more cheaply, and just as well, of earthen embankments. These reservoirs filled when the streams were in flood, and the water was let out in dry times as it was needed.

These reservoirs were not connected by pipes or aqueducts with the city. When water from them was wanted



The Old Croton Dam. This view was taken before the filling of the New Croton Dam, which now entirely submerges the old dam.
(Courtesy of W. H. Sears, Chief Engineer Board of Aqueduct Commissioners.

New Croton Dam. Lower down the stream and now completely submerging the old dam.

the gates on their outlets were opened, and the desired quantity of water was allowed to flow down the natural channels until it came to Croton Lake, as the reservoir formed by the dam first built was called.

Since then impounding reservoirs have been added to the Croton system, one by one, as the needs of the city have grown. The system is now complete, and it will not pay to add others because those now available hold all the flood waters that can be practically utilized from the catchment area, and more reservoirs would not add to the supply.

The amount of water that can be utilized may be stated in this way: On an average 46 inches of rain fall each year upon the catchment area. Of this, one-half is lost by evaporation from the water surfaces, from the surface of the ground, and especially from the leaves of all the plants and trees that grow upon it. The other half, equal to a rainfall of 23 inches, flows off in the streams and sooner or later reaches Croton Lake.

In wet years the amount that flows off is greater, in dry years it is less, than the average. In the winter and spring months the flow is very much greater than at other times.

Now, the principal use of the impounding reservoirs is to hold the excess water of the winter and spring flows and make it available during the summer and fall.

They also serve to a less extent to hold the water of wet years and to make it available in dry years.

The reservoirs all together hold an amount of water equal to a rainfall or runoff of about 18 inches upon the entire catchment area, and it is computed that the

amount of water that can be continuously drawn from the system by the aid of this storage through a dry time is 17.5 inches per annum. This is equal to an average flow of 300,000,000 gallons per day.

The whole average amount of water running off, as measured through a long term of years, amounts to about 23 inches, or 395,000,000 gallons per day, but practically that part of this amount above the 300,000,000 gallons daily actually utilized cannot be made available.

To do it would require reservoirs of extraordinary size to hold the excess from a series of wet years and make it available in a series of dry years.

These reservoirs would cost too much in proportion to the added quantity of water obtained. Further, the gain would not all be utilized, first, because with added water surface there would be more loss by evaporation; and, second, because there would be a deterioration in the quality of the water on holding it so long in reservoirs which would be sometimes full and sometimes empty.

Catskill Supply for New York. A new source of supply for New York City to supplement the Croton supply has been authorized and is now under construction. The catchment area is in the Catskill mountains, nearly a hundred miles as the water flows from New York City

The part of the catchment area first developed is that of Esopus Creek. This has an area of 255 square miles. It is thus considerably smaller than the Croton catchment area. It is the plan, however, to divert several neighboring areas when they are needed, and all the works are built with reference to this end.

In one respect the development is quite different from

that of the Croton. Instead of providing a series of relatively small reservoirs, added from time to time as the needs of the city require, the whole ultimate storage will be provided by one enormous reservoir, called the Ashokan Reservoir. This will hold 132,000,000,000 gallons of water, and will be the largest artificial reservoir for water supply in America, if not in the world.

This reservoir is much larger than it would pay to build for the Esopus catchment area alone. It is built so large in order that it may also serve to store water from the other catchment areas which are to be later diverted to it. It also differs from the Croton development in the manner of drawing the water. All the storage is in one reservoir, and the aqueduct to the city leads directly from it, so that the flow through the natural channel from the upper reservoirs to the lower one on the Croton has no equivalent in the Esopus plan.

Boston Supplies. Boston is also supplied with water from impounding reservoirs upon relatively small streams. The first of these reservoirs was Lake Cochituate, a natural lake taken for the purpose of a reservoir, and since then treated precisely as an artificial reservoir would have been treated.

Cochituate water first entered Boston in 1848, when the city had a population of 128,000, and the capacity of the works first built was 9,000,000 gallons per day.

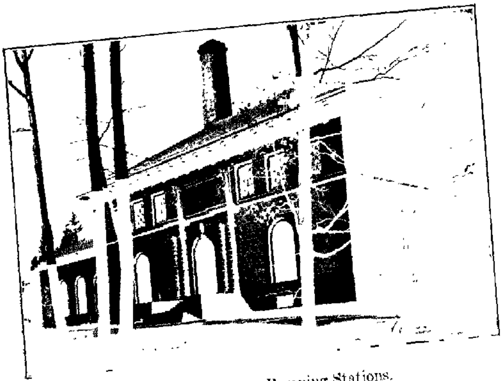
The Mystic works, also making use of a natural lake as a reservoir, were abandoned in 1898, because of the great increase in population upon the catchment area, which was very near to the city.

The Sudbury River water first came to Boston in 1878, as an addition to the Cochituate supply. The catchment area of this river was gradually developed by a series of seven comparatively small reservoirs, added from time to time in the same way that those upon the Croton catchment area were added as needed.

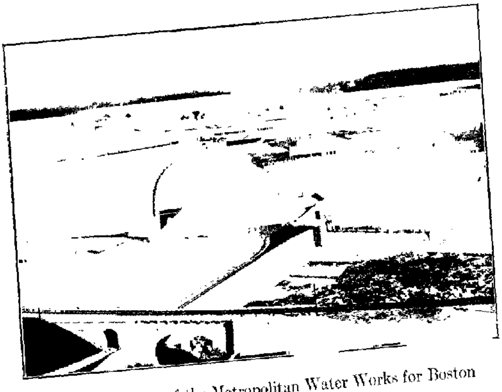
The Sudbury supply becoming inadequate, a further large addition was made in the Wachusett Reservoir, upon the south branch of the Nashua River. The Wachusett water first entered Boston in 1898. As in the case of the new supply for New York, all the storage is in one great reservoir, the Wachusett Reservoir, holding 63,000,000,000 gallons of water. When first built it was the largest artificial reservoir in existence. It was cheaper to build one large reservoir than a series of smaller ones of the same total capacity; and as the resources and growth of the city justified a complete development in this respect at the outset, it was clearly best to do it in this way.

Other Impounding Reservoir Supplies. Baltimore is supplied from impounding reservoirs upon the Gunpowder River, and many large and small cities in the Eastern states are similarly supplied. Among them are Newark and Jersey City, New Jersey; Worcester, Cambridge, and Springfield, Massachusetts; New Haven and Hartford, Connecticut; Altoona, Pennsylvania, and many others.

Reservoirs only Partially Connected with their Catchment Areas. Many impounding reservoirs have been built larger than could be filled from the catchment areas naturally tributary to them, and additional areas have



One of the Boston Pumping Stations.



Wachusett Dam of the Metropolitan Water Works for Boston and Suburbs.

Courtesy of Dexter Brackett, Chief Engineer Metropolitan Water Board.

been made partially tributary to them to insure their being filled. At Hartford, Conn., for example, side-hill or contour ditches are used to considerably extend the natural catchment areas.

It only occasionally happens that the channels provided in such cases are large enough to carry the largest flood flows or tight enough to hold all the dry weather flows. Usually, therefore, more or less water is lost in such connections, and the quantity of water available is correspondingly less.

At Lynn, Mass., an additional area is made available by means of pumps which lift water when the natural flow is sufficient from the Saugus River to a reservoir too large to be filled from its own catchment area. The Staines reservoirs for London, England, operate in the same way; that is to say, the flood flows of the Thames are pumped to them, to be let out again when there is need of the water.

Impounding Reservoirs with Pumping. By far the greater number of impounding reservoirs are elevated above the cities which they serve, and water flows from them by gravity to the places where it is to be used. But there are cases where the reservoirs are not high enough to allow this to be done. This is particularly the case along the sea-coast, and in general where the ground is comparatively flat and the catchment areas but little elevated above the cities which they serve.

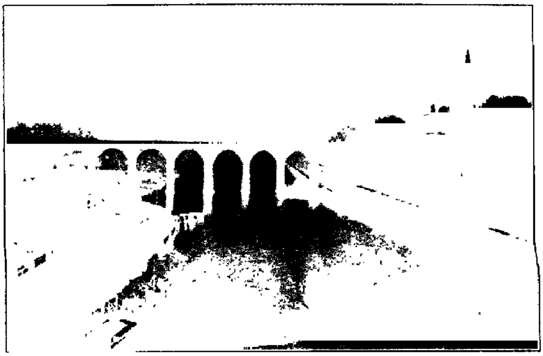
Gloucester and Lynn, Mass., pump all their water from impounding reservoirs located but little above tide-level, and similar arrangements are in use at Charleston, S. C., Norfolk, Va., etc.

Columbus, Ohio, should be mentioned in this connection. The Scioto River, with a catchment area of 1032 square miles above the water works' intake, usually, supplies all the water that is needed. But in dry times there is not enough water naturally flowing in the river. The city has built a masonry dam 46 feet high, holding in reserve 1,627,000,000 gallons of water to help maintain the supply during dry times, with provision for increasing the reservoir when the growth of the city requires it. The Columbus supply, while in most respects to be classed as a river supply, comes to a certain extent within the class of impounding reservoirs which require pumping.

Impounding Reservoirs in the West. Denver is supplied in part with water from an impounding reservoir upon the South Platte River. The dam is of stone masonry, with a maximum height of 235 feet, and holds 24,000,000,000 gallons of water.

San Francisco and Oakland are also supplied from large impounding reservoirs. Two or three years' supply are held in reserve in these cases. This is a far larger allowance than is provided in most Eastern cities where the reserve rarely reaches a year's supply, and sometimes is only sufficient to last for a month or two.

The reason for the very great amount of storage needed at San Francisco is to be found in the great inequality of the rainfall. There are often years, and sometimes two years in succession, when the natural runoff is not large enough to maintain the supply. Reservoirs must therefore be provided to fill in the year when there is rain, and to maintain the supply when there is but little rain;



High Bridge in 1907. Built about 1840 to carry Croton water across the Harlem River to New York City.

Lake Cheesman Dam and Reservoir. Denver Union Water Company.

and experience shows a reserve for a period of three years to be necessary.

This is a far different condition from that of the Eastern states, where a substantial runoff can be counted upon every winter.

Computation of the Amount of Storage Required. This must be based upon records of runoff or flow of the stream, for which calculations are to be made, covering a series of years.

In case such records are not obtainable, as is often the case, an estimate may be based on calculations resting upon the actual records of streams which have been measured and which are believed to be similar to the one under consideration.

Very good records of the flow of the Croton River are available. There are also good records of the Sudbury River. Both of these go back to about 1870. They are particularly valuable because there were some very dry years about 1881–3, and these records cover this period. For more recent years there are more available records. The runoff from the Wachusett catchment area, from the Pequannock catchment area of the City of Newark, and some others have been measured.

In addition, the United States Geological Survey has measured the flows of many streams in the last years. This work is most helpful, though unfortunately an effort has been made to do more work than the means at hand would permit to be done well, and many of the results must be used only with considerable caution.

Rainfall records are easier to get and are much more generally available than runoff records. They are of

some help in comparing different streams, and especially in comparing a given dry period for which the runoff has been observed with other dry periods for which there are no runoff records. Even in such cases rainfall records are apt to be misleading, because there is no close relation between observed rainfall and runoff. In almost every long continued record it is found that the year of least rainfall is not the year of least runoff.

In general it may be said that for Southern New England, and for New York, south of the Catskill Mountains, and for Northern New Jersey (and this is the region in the United States where impounding reservoirs have been most extensively used) fairly good estimates of the amount of storage required to maintain a given supply from a given catchment area may be made by a proper application of the published figures of flow from the Croton, Sudbury, and Wachusett catchment areas. Outside of this region the data for computing runoff, and the required amount of storage are less numerous and less exact, and the accuracy of the computation must therefore be less, even when made by the best qualified engineers.

In a general way, within the limits above noted, with a storage of 11.5 inches of runoff, or 200,000,000 gallons of water per square mile of catchment area, a yield of 16.8 inches, or 800,000 gallons per day per square mile may be counted on, and one-half this quantity of water can be secured with one-fourth this amount of storage, as shown by the following table. Land area only is counted in these calculations, that part of the catchment area which is covered with water being excluded, as the

evaporation from it nearly equals the rainfall in a dry year.

STORAGE REQUIRED IN GALLONS PER SQUARE MILE OF LAND SURFACE TO PREVENT A DEFICIENCY IN THE SEASON OF GREATEST DROUGHT WHEN THE DAILY CONSUMPTION IS AS INDICATED.

Daily Yield.		Storage Required.	
Gallons per sq. mile.	Inches per annum.	Gallons per sq. mile.	Inches of runoff.
200,000	4.2	10,000,000	0.6
300,000	6.3	30,000,000	1.7
400,000	8.4	50,000,000	2.9
500,000	10.5	75,000,000	4.3
600,000	12.6	100,000,000	5.8
700,000	14.7	140,000,000	8.1
800,000	16.8	200,000,000	11.5

It must be remembered that even within the limits of area mentioned there is considerable difference in yielding power of catchment areas, and these can be to some extent allowed for when sufficient data are at hand.

It does not make very much difference in case of partial development whether all of a catchment area is tributary to the reservoir or only a part of it, provided that the reservoir, and every reservoir, if there are more than one, must have catchment area back of it, so that the least winter runoff, which may be taken roughly at 12 inches, will completely fill it after it is empty.

The above figures apply only to the area mentioned. In other parts of the country the conditions of runoff are widely different.

Care of Catchment Areas. The catchment areas supplying impounding reservoirs, and the natural ponds and lakes used as reservoirs, are limited in area, when compared, for example, with the catchment areas of the

great rivers from which many public water supplies are drawn. It is, therefore, possible to inspect them in a sanitary way and to keep track of what is taking place upon them. It is usual for cities to devote some attention to this subject.

The ideal catchment area is free from human habitation and is covered with forest. Lynn, Mass., and Hartford, Conn., own all or practically all of the catchment areas of some of their reservoirs, and are encouraging forests to grow upon them. It has not been possible to extend this policy to all catchment areas. This is because the growth of the cities is such that when a certain catchment area is well in hand, another and larger one must be taken to maintain the supply, and a long time must elapse before that can be brought to the standard.

It is often impossible to remove population from a catchment area, and, in fact, it is usually unnecessary to do so. Very good water is drawn from areas upon which there is much population, when proper and well known precautions are taken. There are 775 people per square mile upon the Cochituate catchment area, 292 upon the Sudbury, 45 upon the Wachusett, and 69 upon the Croton, yet it is not to be supposed that the waters drawn are seriously impaired by these populations. And as better means of handling the water are used, the influence of population upon the quality of the water becomes less.

The storage of water in large reservoirs tends strongly to improve its sanitary quality. Disease germs, if they are present, die in water in such storage. In our climate,

at least, they never grow in storage reservoirs, and, if introduced, the length of time that they can live is limited. This is practically what makes the Boston water and the New York water relatively safe. The greatest danger is that some polluted water will sometimes get by the reservoir, or flow through it by some short cut, and so reach the consumers before it has been subjected to full storage conditions for a sufficient length of time.

Further, the influence of the population upon the quality of the water in the future will be less than it now is, because it now seems clear that in order to improve the physical character of the water, as will be explained at length, the water of these reservoirs is sure to be subjected to some process of purification before delivery, and when this is done such effects of pollution as there may be will largely be removed at the same time and by the same means.

There is therefore no real reason for attempting to turn back into their primeval forested state the cultivated and populated areas from which it is necessary to take the water to supply our cities. The practice of Boston, New York, and many other cities is sufficient, and this practice may be briefly stated as follows:

There is a sanitary inspector who makes himself familiar with the whole catchment area. Suitable laws give authority. Manufacturing wastes and human wastes are kept out of the main streams and the smaller tributaries of the catchment areas. Where expense is involved to remove old sources of pollution, the city pays it, and new sources of pollution are not permitted. The city owns the shores of the reservoirs, and also

often the land along the more important streams. Sometimes properties that are especially likely to pollute the water, as, for example, old mills using water power, are acquired by purchase or condemnation. In these ways the grosser pollutions are kept out of the water by the city, and the rural population upon the catchment area remains comparatively undisturbed.

The purchase of all unoccupied lands on the catchment areas, which can be bought at fair prices, is often to be recommended, but it has not often been carried out.

The development of manufacturing and suburban centers upon catchment areas, especially where there is good train and trolley service, and other favorable conditions, is more to be feared. Such developments will no doubt lead ultimately to the abandonment of some of the Boston catchment areas, and perhaps at a later date of the Croton, and some others, and the substitution of other, larger and more remote areas.

But the possibilities of water purification, as yet but slightly realized, must be taken into account, and it may be a long time before this happens.

Stagnation of Water in Impounding Reservoirs. In our climate, when a reservoir or lake is more than from 20 to 40 feet deep, the upper part of the water is usually in circulation under the influence of the wind, and the lower part remains stagnant. There is little or no mixing between the surface water and the bottom water, except for two short periods each year, one in the spring and one in the fall. These periods of circulation to the bottom are known to water works

men respectively as the spring turnover and the fall turnover.

At the time of the spring turnover all the water mixes from top to bottom and has a temperature approximately that at which water has its greatest density, namely, 39° F. Afterwards the sun warms the surface water above this temperature. This makes it lighter, and then it will not go down again to mix with the colder and heavier water below, but remains at the surface.

The wind stirs it up for a certain depth. This depth is about 20 feet in small reservoirs and about 40 feet in the great lakes. In this surface layer the temperature may rise in midsummer at the surface to 75° or 80° or more.

Below, the water is cooler, and some distance down it rapidly falls to the temperature of the whole mass of the bottom water. And this bottom layer to within 20 or 40 feet of the surface, depending upon the size of the reservoir, remains quiet and stagnant and unmixed with the surface water from spring until fall. Its temperature gradually and slowly increases, but it is always cool and still.

In the fall the temperature of the top water falls, until it approaches that of the bottom water. As the difference is less the wind action extends deeper, until, all at once, often when the wind is blowing, all the water in the reservoir turns over and mixes from top to bottom. The mixing continues for a few weeks, until the temperature of the surface water falls below the point of maximum density. Then the colder water commences to accumulate at the top. The top often freezes and entirely shuts

out wind action, so that the period of winter stagnation is even more quiet than the summer period. It is terminated by the warming of the surface water in spring, until it reaches the temperature of the bottom water, when the spring turnover again takes place.

Now, this phenomenon of stagnation has much to do with the quality of the water.

Without attempting to go into the chemistry of the processes, the most important conditions are these: In the brief period of circulation following the spring turnover, the water contains normally a large amount of oxygen or air in solution, as does almost any pure natural surface water. And when the period of summer stagnation sets in, the bottom water is well charged with this oxygen. Now, on the sides and bottom of the reservoir, in contact with this stagnant water, there is much organic matter, and further quantities of organic matter settle down from time to time from the warmer surface water. These are in the form of the dead or living bodies of organisms that have grown in the warm surface water in the sunshine and have then sunk away from it into the cool dead water below. Now, the organic matter on the bottom, and that coming down from above, soon start to ferment and decompose and become oxidized. That is to say, they are converted back into their constituent elements, and this is done at the expense of the oxygen held in solution in the water. This oxygen lasts for a time, but long before the summer is over it is all used up.

In the absence of oxygen (for there is no more below, and without circulation there is no way that it can get down from above) the organic matters still continue to

decompose, but they decompose in another way. The decomposition that takes place in the absence of oxygen is called putrefaction. Now putrefaction produces some vile odors and nasty tastes. It is largely because of these odors and tastes that we are interested in it.

These odors and tastes accumulate in the bottom water until the fall turnover; then they become mixed with all the water in the reservoir. And if the water is drawn from the reservoir near the top, as it usually is, there will be a great change in the quality of the water on the day of the fall turnover.

These odors and tastes will make an impression upon the quality of the water at other times. Reservoir outlets at certain levels do not draw water from those levels only as is sometimes supposed. Instead, they draw somewhat from all directions where there is water; from above and from below, as well as from the plane of their own levels. And so, in the natural course of events, even though water is drawn only from the top, some bottom water will be drawn with it, and the odors and tastes of putrefaction will be carried to a greater or less extent with it into the supply.

The odors and tastes of putrefaction are rapidly dissipated and destroyed by exposure of the water containing them to the air. But to effect this dispersion the exposure must be in some active or even violent way, such as playing through a fountain, or falling over a dam, or flowing in a rapid, strong current down the natural bed of a stream with a rapid fall.

In the Croton system this effect of aeration to disperse the odors and tastes of putrefaction is used to a large

extent. Most of the storage reservoirs are high in elevation above Croton Lake. When water from them is needed, it is the bottom water which is mainly drawn. This water, often foul smelling as drawn, rapidly cleans itself as it flows through the outlet fountains and over the rocky channels to the lower reservoir, from which it flows to the city. The old Croton Lake was too small to develop putrefactive action on its own account to an objectionable extent, and so the city was substantially free from the odors and tastes resulting from putrefaction.

The new Croton dam, making a reservoir taking the place of the old Croton Lake, but vastly larger, has not improved conditions in this respect. The results of putrefaction in it are more noticeable in the city.

Putrefaction is not universal in stored waters. Many lakes and a few very clean reservoirs are free from it.

Reservoirs less than 20 feet deep are kept in circulation by the wind to the bottom all summer, and in general the phenomenon of stagnation and putrefaction do not take place in them. In many cases, however, with dirty bottoms and strong growths of weeds and organisms, putrefaction does take place in the lower part of even quite shallow reservoirs. Unmistakable evidences of this, for example, have been found in the Ludlow Reservoir at Springfield, Mass., and even in the extremely shallow Goose Creek Reservoir at Charleston, S. C.

Odors and Tastes from Growths of Organisms. Many kinds of organisms grow in impounding reservoirs, ranging all the way from the humblest germ to the full-grown fish and lily-pad. Most of these organisms do no particular harm, but some of the kinds are extremely

troublesome. They are troublesome principally because of the odors and tastes which they produce in the water. Some of these come from essential oils which the organisms produce and liberate during their growth, and some of them result from the death and decay of the bodies of the organisms. Some of the troublesome organisms feed upon other organisms or their remains. These, in a general way, may be compared to the higher animals. Some of these may grow and become troublesome in winter under the ice. But the most troublesome organisms are the algæ and other microscopic organisms which grow in the sunlight near the surface of the water.

These organisms are comparable to the higher plants. They do not depend upon organic matter or the bodies of other organisms for their food supply. They require only the carbonic acid and the nitrogen and the mineral matters always present in the water and in the air, and the sunshine for their growth. And from these simple materials they build up the matters which compose their bodies, and which give rise to the odors and tastes, just as a tree builds up its own substance from the mineral matter of the soil and the carbonic acid of the air, with only the help of the sunshine.

Where there is considerable population upon the catchment area of a pond or reservoir, the pollution reaching the water from it serves as a food supply for certain organisms and stimulates their growth to a noticeable degree.

There are many kinds of algæ, and they differ greatly in their odor-producing powers. Practically all American impounding reservoir waters suffer from them, but

some far more than others. English reservoirs seem to be comparatively free from them, probably because of the lower temperatures of the surface waters. English reservoir surface temperatures do not often stay long above 60° F. and seldom go above 65°. American reservoirs have temperatures fully 10° higher in summer, and this seems to be the most important point of difference.

In some Australian impounding reservoirs, very high surface summer temperatures are obtained, and strong growths take place; but it does not appear that the odors and tastes produced by sub-tropical conditions in Australia, and in the southern part of the United States, are as much more objectionable when compared with those in the climate of New York, as might be reasonably inferred from the very great increase in the amount of such trouble in the climate of New York as compared with English conditions.

Growths often do not occur in a particular reservoir supply because it is not seeded, but there is no known way of preventing seeding.

A certain degree of quiet and repose is necessary for the development of the organisms. This is why they never grow in rivers and flowing water. Wave action from wind also prevents growth, and this seems to be one reason why large lakes and reservoirs are less troubled by them than smaller ones.

Most American impounding reservoirs are arranged to have water drawn from their surface-layers, to avoid the odors and tastes of putrefaction in the bottom water; but it sometimes happens that the surface water is even more objectionable than the bottom water because of odors and tastes of living and dying organisms.

Stripping. In Massachusetts more attention has been given to protecting the quality of reservoir waters than elsewhere, with a view to avoiding objectionable odors and tastes.

Shallow flowage has been cut out of many reservoirs, partly by diking off shallow portions, and partly by filling them with material excavated from other shallow portions. This has had the effect of reducing the area of a reservoir, and of increasing its average depth.

But by far the most extended and costly work has been the stripping. By stripping is meant the removal of the surface soil from the area that is to be covered with water. At least eight considerable reservoirs, in addition to many smaller ones, have been stripped in this way, namely:

Reservoir.	City supplied.	Area in acres.	Average depth in feet.	Capacity in million gallons
Wachusett . .	Boston . . .	4,200	46	63,100
Sudbury	Boston . . .	1,292	18	7,253
Lower Hobbs . .	Cambridge .	467	10	1,450
Framingham No. 3 .	Boston . . .	253	15	1,183
Hopkinton . . .	Boston . . .	185	26	1,521
Upper Holden . .	Worcester . .	185	17	794
Ashland	Boston . . .	167	26	1,464
Lower Holden .	Worcester . .	149	15	742

The object of stripping has been to remove the organic matter of the surface soil. Where this has been thoroughly done, it has tended to improve the conditions of the water in the reservoir. In the older reservoirs prepared in this way putrefaction in the bottom water has not taken place for some years after the reservoirs were built, although in other cases putrefaction seems not to have been entirely prevented, even at the outset.

The removal of the soil also seems to cut off a part of the food supply for objectionable organisms, and the stripped reservoirs have suffered less from these growths than other reservoirs similarly situated but not stripped.

But stripping does not prevent objectionable growths; it only reduces them somewhat, and it does not always permanently prevent putrefaction in the bottom water.

It does not prevent the growths, because some of the worst of the organisms do not need or make use of the organic matter of the soil as a food supply. Instead, they live on the mineral matters of the water and the air, and with the aid of the sunshine they build up their own organic matter precisely as the higher plants do in growing in soil. Removing the soil from a reservoir site does not seriously or permanently interfere with the growth of these organisms. Further, it cannot be depended upon to permanently prevent putrefaction, because in our climate there seems to be an inevitable accumulation of organic matter on the bottom of all ponds, except those which are so large that the wind action is able to hold the growths of organisms down, and the accumulation of the bodies of dead organism on the bottom soon furnishes the materials for putrefaction even though all soil with its organic matter was removed at the start.

This accumulation comes from the bodies of organisms which grow in the sunshine in the top water and then settle through the stagnant bottom water to the bottom. It is inevitable and cannot be prevented. It is an accumulation of this general character which has filled with peat most of the lakes that were left by the

glacial epoch, and has changed them into the peat swamps so common in all our Northern states.

Stripping is an expensive process, but the quality of a public water supply is an important matter, and in some cases the cost has been justified by the improved quality of the water.

In other cases there seems to be no reason to doubt that more improvement could be effected in other ways, at less cost as, for instance, by aeration and filtration of the water.

On the Use of Copper Sulphate. In 1904 Dr. George T. Moore, of the United States Department of Agriculture, proposed the use of sulphate of copper in impounding reservoirs, to poison the organisms which produce objectionable odors and tastes. This substance is extremely poisonous to some of the organisms and only moderately poisonous to man. It is therefore possible, with due care, to kill the algæ without endangering the health of the people who use the water.

The method of treatment proposed and generally used is to put weighed quantities of the copper sulphate in loose cloth bags and tow them back and forth with row-boats through the water of the reservoir until the material is dissolved. One part of copper sulphate in from four to ten million parts of water suffices to destroy growths of some objectionable organisms. Others require larger doses. Some of the copper combines with the bodies of the organisms and settles with them to the bottom, and in this way is removed from the water. If the water is hard, more copper is removed in this way, and it goes out quicker. If the water is afterwards filtered most of the remaining copper is removed.

As copper is but slightly poisonous to man, there does not seem to be any real danger in the use of copper in this way, or even in the use of the somewhat larger doses which have occasionally been used where the water was very bad.

The copper kills some kinds of organisms, but not all kinds, and to some extent its use clears the way for stronger growths of the forms that are not killed. It therefore changes the kind of growth in a reservoir to some extent, and this change is frequently accompanied by a great improvement in odors and tastes.

The use of copper sulphate does not prevent, or even materially reduce, putrefaction, and the tastes and odors resulting from it.

This method of treating water is cheap, easily and quickly applied, and considerable good has come from it. The correction is only partial, however, and not always permanent. It is not therefore to be relied upon in all cases.

Color in Reservoir Waters. Most reservoir waters are colored yellow to a greater or less extent by peaty matter. This coloring matter is extracted from dead leaves, from soil, from peat, etc. It seems to be the same material as the coloring matter of tea, and it is certainly harmless. But it makes a water less pleasing in appearance, and great efforts have been rightly made to prevent it and to remove it.

When a colored water is exposed to sunlight it is gradually bleached. A long period of exposure is required for completing bleaching, but a notable reduction in color due to this cause is usually found in all considerable

impounding reservoirs. Some of the Boston reservoirs have been made larger than would otherwise have been necessary and desirable for the sake of allowing more bleaching to take place in them.

A large part of the color comes from swamps upon the catchment areas. When swamps are drained, the color of the water issuing from them is reduced.

The upper Mississippi is a highly colored stream. There are thousands of square miles of swampy land upon its catchment area. In the last decade much of this land has been drained to allow its use for agricultural purposes. Only a fraction of the whole amount of swamp area has been drained, but the change thus far made has reduced to a noticeable extent the color of the water of the river at Minneapolis.

In the Boston water works thousands of acres of swamp upon the catchment areas of the various reservoirs have been drained by the city, with the consent of the owners of the land, for the purpose of reducing the color of the supply. A considerable reduction in color has been so made.

If there were no other ways of reducing color, bleaching in reservoirs and drainage of swamps would be worthy of most careful attention and frequent use. But at the present time other means of removing color are known which usually accomplish more for a given expenditure than can be reached in these ways. These will be described in connection with methods of water purification.

CHAPTER II.

WATER SUPPLIES FROM SMALL LAKES.

The city of Rochester takes its supply from Hemlock Lake, thirty miles from the city and elevated above it so that water flows by gravity under sufficient pressure. In the same way the city of Syracuse uses the water of Skaneateles Lake.

These cities were fortunate in finding these lakes, which are really impounding reservoirs ready-made and suitable for their needs. Some expenditures were necessary to acquire the water rights, and to buy some of the shores, and to secure sanitary protection of the quality of the water; but broadly speaking, these reservoirs were gifts of nature to these cities, and if they had not been there, the cities might, and probably would, have spent hundreds of thousands, or millions, of dollars in building reservoirs less suitable for their purposes than those freely provided by nature.

In taking such a lake with a limited catchment area, provision must be made for raising and lowering the water surface within certain limits. This is done by building a dam at the outlet, or by putting in an outlet pipe at a lower level than the natural outlet, or by doing both at once. This provides the necessary storage capacity to hold the winter and spring flood-flows, and

to allow them to be drawn and used when needed in the dry summer months.

And when this is done the natural lake serves precisely the same purpose as an artificial reservoir, and the water is subject to the same troubles. The sanitary protection of the catchment area, the stagnation and putrefaction of the bottom water, and the growth of organisms in the top water, are all pretty much the same as in artificial reservoirs.

On the whole, the waters of natural lakes and ponds are less subject to objectionable odors and tastes than are the waters of artificial reservoirs, and putrefaction is less troublesome, but the difference is one of degree, not of kind.

Growths of organisms are less frequent and strong, probably because the lakes are larger and deeper and more completely subject to, and controlled by, wind action, and putrefaction is less prevalent because there are fewer organisms growing in the top water and settling down into the bottom water to cause it.

The advantages of taking a natural lake for a reservoir are so great and obvious that it has nearly always been done where circumstances have permitted. Both New York and Boston have utilized a number of lakes upon their catchment areas in this way, though the reservoirs mainly depended upon have been artificial. Portland, Maine, is supplied from Sebago Lake. St. Paul is supplied from a number of small lakes. In this case the lakes are not high enough for a gravity supply, and the water is pumped.

Throughout the northern part of the United States, where the country has been glaciated, and small lakes abound, innumerable smaller cities and villages are supplied from them, sometimes by gravity and sometimes by pumping.

CHAPTER III.

SUPPLIES FROM THE GREAT LAKES.

Most of the cities on the shores of the Great Lakes use water taken from them by pumping. The largest of these cities in the United States are Chicago, Cleveland, Buffalo, Detroit, Milwaukee, and Duluth. They also in general put their sewage into the same water from which their supplies are taken. And the relations between the water supply and the sewage are most interesting and important.

In one respect two of the cities are more favorably situated than the others. Buffalo and Detroit are upon strong running streams at the outlets of the lakes, where it is possible to take the water supplies from points above the cities, and to discharge the sewage at points below, with little likelihood of subsequent mixing. And in this respect the water problems of these cities are much simpler than those of the others.

Buffalo has the advantage over Detroit that the water comes to it more directly from the lake and with less chance of pollution. Detroit is sixty miles below the outlet of Lake Huron, and in that distance there is opportunity for much pollution. This pollution comes both from the drainage of the considerable area reaching the river in this distance and from the discharge of sewage from the cities directly upon its banks. And this pollu-

tion by sewage is an important matter even with a dilution as great as that in the Detroit River.

Milwaukee and Duluth are fortunate in that they are able to reach the lakes with intakes in deep water at points where there seem to be fairly definite currents bringing fresh, clean water from the body of the lake to the intakes, and excluding the city sewage. These currents seem to be dependable, although it may be that they are sometimes reversed temporarily by strong winds. Certainly the present indications are that the water obtained from them is at least comparatively free from sewage.

Chicago and Cleveland have suffered most from the mingling of their own sewage with their water supplies, and their troubles in this respect are not over. Chicago, it is true, has cut a drainage canal to keep her sewage from entering the lake, and to take it instead through tributaries to the Mississippi River, at a cost of over forty million dollars. But even now that the canal is in operation, so much polluting material finds its way to the lake that the water is polluted at times for a long distance out. Cleveland has no drainage canal, but she is smaller than Chicago, and the conditions of the water in the lakes near the two cities probably are not greatly different.

Both lakes are comparatively shallow and are stirred to the bottom by heavy winds, at least as far out as the water works intakes have yet been built. Both cities have spent millions driving tunnels out under the bottoms of the lakes for the purpose of securing water free from contamination. Both have succeeded in getting better water in this way, and both have failed to get

thoroughly good water, even with intakes located four or five miles from shore; and both cities have suffered severely at times, and perhaps a little all the time, from sickness and death caused by the pollution of the lake waters by their own sewage.

The Great Lakes are so large, and the dilution and time intervals and exposure to sun and air are so great that there is no chance of infection being carried from one of the great cities to another. Chicago's sewage would not endanger the purity of Detroit's water supply, even with no drainage canal. The little city of St. Clair, with 2543 inhabitants, only 45 miles away, is far more dangerous to Detroit. In the same way Detroit's sewage is harmless at Cleveland, and Cleveland's sewage is harmless at Buffalo.

Besides the large cities mentioned there are a hundred smaller places upon the shores of the lakes which take their water from them, and there are some other cities which do not use lake water. Toledo, Ohio, finds it cheaper and better to use Maumee River water than to put in the expensive intake and appurtenances which would be necessary to secure lake water beyond the influence of local pollution.

In the smaller cities upon the lakes the mingling of the sewage and water may be relatively just as important as in the larger ones. They have less money to spend; their intakes do not go out so far; their sewers are apt to discharge at the nearest point, sometimes directly in front of the water works intake; the water may be shallow, and stirred by the wind to the bottom; and in short, Menominee's sewage in Menominee's water may be just as bad as Chicago's sewage in Chicago's water.

CHAPTER IV.

WATER SUPPLIES FROM RIVERS.

The following large cities in the United States take their water supplies from large rivers:

Place.	Population. 1910.	Water from what river.	Drainage area above intake sq. miles.	Urban population above intake 1910.	Urban population Per sq. mile.
Philadelphia	1,549,008	Delaware	8,186	360,994	44
		Schuylkill	1,915	257,415	134
St Louis	687,029	Mississippi	700,663	5,750,931	8
Pittsburgh	533,905	Allegheny	11,400	306,117	27
Cincinnati	363,591	Ohio	72,400	2,342,103	32
New Orleans	339,075	Mississippi	1,261,084	12,565,811	10
Washington	331,069	Potomac	11,476	104,980	9
Minneapolis	301,408	Mississippi	19,585	34,438	2
Kansas City, Mo.	248,381	Missouri	163,752	987,624	6
Indianapolis	233,650	White	1,820	76,019	42
Providence	224,326	Pawtuxet	....	0	0
Louisville	223,928	Ohio	91,000	3,247,162	36
Toledo	168,497	Maumee	6,723	157,510	23
Richmond	127,628	James	6,800	29,494	4
Paterson	125,600	Passaic	773	24,905	32
Omaha	124,096	Missouri	322,500	160,684	0.5
Nashville	110,364	Cumberland	12,800	25,894	2
Albany	100,253	Hudson	8,240	472,255	57

In addition to these a very large number of smaller cities and towns take their water from the rivers of the country.

In large parts of the country the rivers are the only

adequate available sources of supply, and they will always so remain.

Sanitary Aspects of River Water Supplies. From an hygienic standpoint the succession of cities and manufacturing establishments on the same river, and the combined use of the river as a sewer and source of water supply is most significant.

On some rivers, like the Merrimack, Hudson, Delaware, Ohio, Missouri, and Mississippi, this succession is particularly impressive, and, when the water has been used in its raw or unpurified state, sickness and death have resulted, and thousands of lives have been lost in this way.

The relation of water supply to sickness and death has been shown with force in many cities, notably at Lowell and Lawrence, Massachusetts, at Albany, New York, at Jersey City and Newark, New Jersey, and abroad at London, Paris, Hamburg, Altona, Berlin, etc. Some of these cities have since abandoned the objectionable supplies. Others have installed purification works which have removed the poisonous qualities of the river waters.

At Lowell a ground water supply was secured to take the place of the polluted river water; at Jersey City and Newark new supplies from impounding reservoirs were substituted; while Lawrence and Albany constructed purification works.

Substitute supplies have also been proposed in a number of other large cities. In some cases such supplies could be obtained, though often at greater expense than can now be afforded; but in many or most cases the river water is the only water that can be obtained in sufficient

amount. Where this is the case there is no alternative. The river water must continue to be the source of supply.

It is possible to purify sewage before discharging it into rivers. If all the cities and towns purified their sewage, and if all manufacturing establishments (which sometimes contribute as much as the cities to the pollution of the streams) did the same, then the river waters of the country would be less polluted, and would be more desirable as sources of public water supply.

Some people believe that all sewage and wastes should be so purified before being discharged, and that the rivers should be so protected from pollution.

A few large cities, notably Worcester and Providence, do partially purify their sewage, and many smaller ones do so. But in very few cases has this been done to prevent the pollution of a public water supply taken from the stream below the sewer outlet. Sewage has usually been purified only in those cases where a local nuisance was created in the stream below the outfall, or at least where such a nuisance was anticipated, rightly or wrongly, in case crude discharge was permitted.

By local nuisance is meant the discoloration of the water, the presence of floating substances objectionable in appearance, the deposition of sewage mud on the bed of the stream, and the production of offensive odors. All of which make, or tend to make, the stream and its banks and neighborhood less desirable for bathing, boating, navigation, business, residence, and, in short, less useful to the public, and especially to those living in or often passing the locality.

Now, whether or not a local nuisance is caused by the discharge of sewage depends upon the relative amounts of sewage and flowing water, and upon the rapidity of current and the temperature, etc. These matters need not be here discussed. It will suffice to state that there are numerous cases where local nuisances are produced which would amply justify the purification of the sewage to prevent them, but that in other cases, and, in fact, in a great majority of cases where sewage is discharged into rivers, there does not result any local nuisance which would justify, to prevent it, the expenditure of the money necessary to purify the sewage, or, even if the work could be done for it, of one-tenth of the required sum.

Where sewage is purified to prevent a local nuisance in a stream from which a public water supply is taken below, then certainly the purification is advantageous to the quality of that supply; but this is the exceptional case and not the common one. To set about cleaning up the rivers of the country for the purpose of improving the quality of the public water supplies would involve the purification of sewage from thousands of cities and towns where that was the only reason for the purification, or, in other words, where there was no local nuisance produced by the discharge of crude sewage.

To protect the water supply of Louisville, it would be necessary to purify the sewage of Cincinnati, Pittsburgh, and hundreds of smaller cities upon the Ohio River and its tributaries. From the standpoint of local nuisance, the purification of the sewage from a few of these cities is already necessary, and, as time goes on and population increases, it will be necessary to treat the sewage from

an ever increasing number of cities in this way; but the fact must be fully recognized that the discharge of crude sewage from the great majority of cities is not locally objectionable in any way to justify the cost of sewage purification.

Looking at the whole matter as one great engineering problem, it is clearly and unmistakably better to purify the water supplies taken from the rivers than to purify the sewage before it is discharged into them.

It is very much cheaper to do it in this way. The volume to be handled is less, and per million gallons the cost of purifying water is much less than the cost of purifying sewage.

It is also very much more effective to treat the water, because the methods of water purification are more efficient in stopping germs of disease than are the methods of sewage purification.

It is also more effective, because all the water used can be with certainty treated, while it is well known that very few sewage purification works treat all the sewage from the districts which they serve. There are storm overflows; there is the street wash that may not pass through the sewers; there are the thousand minor pollutions that practically cannot be stopped, even though the sewage is treated and all reasonable precaution taken in connection with it.

It is, therefore, both cheaper and more effective to purify the water, and to allow the sewage to be discharged, without treatment, so far as there are not other reasons for keeping it out of the rivers. It seems unlikely that a single case could be found where a given

and reasonably sufficient expenditure of money wisely made could do as much to improve the quality of a given water supply when expended in purifying sewage above, as could be secured from the same amount of money in treating the water. Usually I believe that there would be a wide ratio: that one dollar spent in purifying the water would do as much as ten dollars spent in sewage purification.

The water works man therefore must, and rightly should, accept a certain amount of sewage pollution in river water, and make the best of it. Taking it up in this way he will master the situation by purifying the water. Success in supplying good water cannot be otherwise reached.

The general project of keeping all sewage out of rivers is attractive, and it will always have its earnest advocates; but it is not a practical proposition and it is not necessary. It is not even desirable, when the greater good to be secured by a given expenditure in other directions is taken into account. Although the public is ignorant of such matters, still, in a general, indefinite sort of a way it does even now understand some of the elements of the situation, and as time goes on it is bound to understand them better.

Turbidity. After sanitary qualities there is no feature of river water supplies of more general interest and importance than the turbidity, or muddiness of the water. All river waters are more or less turbid, but the differences are very great indeed. They come principally from differences in character of the catchment areas.

The Merrimack and Connecticut Rivers in New Eng-

land, draining areas largely covered with glacial drift of a sandy character, are but little subject to turbidity. As an annual average they do not carry more than ten parts per million of suspended matter. Usually they carry much less than even this small amount; but once or twice in a year there is a flood which washes away some of the banks and carries along a considerable amount of silt, but even this rapidly settles out when opportunity presents.

Of the same general character in this respect are the waters of the Upper Hudson and of the rivers of Northern New York, Michigan, Wisconsin, and Minnesota, including the upper Mississippi, and also most of those of northern New Jersey. Small streams rising near the coast and in the sand hills back of it are also found here and there all down the Atlantic coast which are not greatly subject to turbidity. Some waters from mountainous regions where the rocks are hard are also nearly free from turbidity. Such streams are found near the Pacific coast in the Sierra and coast ranges.

Speaking generally, the rest of the river waters of the country are more turbid. Some of them, it is true, are usually fairly clear, and are only subject to excessive turbidity for short intervals in infrequent floods. Such are the Delaware, the Allegheny, and some of the streams in northern Ohio, Indiana, and Illinois.

Farther south the turbidities run higher and also last longer. The larger streams flowing to the Atlantic coast south of the Delaware have very turbid periods and are usually subject to very rapid fluctuation in turbidity. A sudden storm may increase it a hundredfold in a few hours. The Ohio River and its southern tributaries are

subject to large amounts of turbidity, and muddy water sometimes flows in them continuously for much longer periods than in the Atlantic coast streams.

The Missouri River carries the largest amount of sediment of any of the rivers largely used for water supply, and as an annual average the amount runs as high as 1200 or 1500 parts per million. In winter it falls to 200 parts or less, while in midsummer it rises for weeks, and even months, to 5000 parts or more.

The Mississippi at Minneapolis is not much subject to turbidity. As it flows south it becomes more turbid, but even as far down as where the Missouri joins it, it is comparatively a clear water stream. Below, it takes more largely of the character of the Missouri. The amount of sediment is less than in the Missouri, but the Ohio and other tributaries bring to it a sediment that is more finely divided and more difficult of removal, so that for practical purposes the river at New Orleans is as turbid as it is at St. Louis, even though the analytical results show less suspended matter.

Color in River Waters. The color of water has already been mentioned in connection with impounding reservoirs. The color referred to is the yellow color extracted from dead leaves, from swamps, etc. This color is in solution, and it is to be sharply distinguished from the turbidity which results from clay and other suspended matter in the water. Turbidity is frequently spoken of as color; and when the material composing it is colored, as for instance, red clay, it is certainly correct to speak of it in this way. But for the purpose of this discussion color means only the yellow coloring matter that is in

solution. This is the meaning that is commonly adopted by water analysts, and the distinction is necessary.

In a general way, colored waters are found in those regions where turbidity is not found. But there are some exceptions to this rule. The upper Delaware, among the larger rivers, is comparatively free from color, and also is usually free from turbidity. There are many smaller streams of which this is also true. Spring water streams, in sand hill districts, and mountain streams frequently have these qualities. On the other hand, the upper Mississippi is a highly colored stream, and it is also occasionally moderately turbid.

In general, water flowing from swamps is colored, and in a rough way the color of a river water is a measure of the amount and character of the swampy area upon its catchment area.

Many of the smaller streams of the north, from Maine to Minnesota, are highly colored. So also are the smaller streams from the swamps near the coast flowing to the Atlantic all the way down the coast to Florida. Some large rivers are colored to an extent which affects materially their value for water supply purposes, although they are never as highly colored as some of the smaller streams. Among the rivers colored so as to affect their value, and which are important sources of public water supply, may be mentioned the Merrimack, Hudson, Black, Passaic, Grand, and Mississippi Rivers. There are also many others supplying smaller cities.

Turbidity and color render water less attractive, less desirable, and less valuable for public supply. They can be removed by purification methods, and their removal

is now generally demanded, although there are still many cities supplied with water generally regarded as good but which is subject to them in considerable amounts. This is especially true of color.

It is only within the last few years that accurate records of turbidity and color have been kept. Even now they are kept by only a part of the water works that are affected by them; and naturally even less is known about the turbidities and colors of the waters of rivers that are not used for water supplies. Our knowledge of the general distribution and range of turbidity and color is far short of what could be desired. It is being added to rapidly, however.

CHAPTER V.

GROUND WATER SUPPLIES.

WATER drawn from the ground by wells or taken from springs is called ground water, and this source of supply is a most important one.

It is easier in proportion to get a little ground water than to get a larger amount, and for this reason ground water supplies are more generally available for, and better adapted to, the needs of small places than of large cities.

If the water supplies of the country could be all counted up, each plant counting for one regardless of its size, it would be found that the ground water supplies were more numerous than those of any other kind, probably in fact more numerous than all the others put together. But as the average size of the ground water supplies is small, the total amount of water supplied from them would be much smaller than that supplied from impounding reservoirs, or from rivers.

In Europe ground water supplies have been secured for many large cities. There are no corresponding developments in America. The reasons for the greater use of this method of supply in Europe are:

1st: Smaller quantity of water required per capita.

2d: More favorable geological conditions.

3d: More study given to the subject, and greater efforts made to secure them, especially in Germany.

Without discussing these points in detail it may be said that few large American cities are situated where there are sufficient beds of sand and gravel, or other previous formations to yield water for their supply, such as exist over a considerable part of central and northern Europe, and which have been drawn upon most successfully by even the largest cities.

Ground Water from Sand and Gravel Deposits. Occasionally there are locations where such supplies, comparable to the more important European supplies can be secured in America. Of these none is more favorable than that of the Brooklyn water works of the city of New York. Of the total supply of 142,000,000 gallons daily, 96,000,000 gallons, or 68 per cent, is obtained from the ground, mostly from tubular wells driven in the coarse, open sand and gravel. These wells are in groups, each group being pumped by a pumping station, which throws the water into a collecting conduit, which takes it to other pumps, which finally raise it for the city service. The ground water is not kept separate, but is mixed in the conduit with the pond and reservoir waters, which make up the balance of the supply.

Separating the works into so many small units, each with its own pumping station, adds greatly to the cost of securing the water, but either this or its equivalent seems to be necessary.

Only so much water can be secured from a square mile of ground. The amount depends upon the rainfall, upon the evaporation from the surface of the ground and from the vegetation, and upon the amount of storage in the pores of the soil. And all these matters may be

computed in much the same way that the yield of an impounding reservoir can be calculated. The yield is measured by the rainfall, in a dry year, less the evaporation; and the available yield is either this amount, or that part of it which can be maintained as a steady flow throughout the year by the storage in the pores of the earth. Most of the available yield is collected during the winter when evaporation is slight, and the supply must be maintained through the summer by the reserve thus accumulated.

At Brooklyn the conditions for storage are most favorable, and it is estimated that 750,000 gallons per day can be drawn from each square mile of catchment area.

Water flows through sand only with some difficulty. From a given pumping station it is only possible to draw the water for a limited distance. This distance depends upon the depth and coarseness of the sand. The area that can be served by one pumping station is considerably extended by the use of wells at some distance from each other, connected by pipe lines leading to the pumps. But practically there is a limit, and the only way to secure a large quantity of water is by the use of a number of comparatively small pumping stations, separated so as not to draw from the same territory. In Brooklyn, to secure 96,000,000 gallons of ground water per day, twenty-four separate pumping stations are used. From one infiltration gallery 15,000,000 gallons per day are obtained. Otherwise the greatest average quantity of water from one station does not exceed 6,000,000 gallons daily. And the average quantity from one station is only about 4,000,000 gallons daily.

The favorable conditions at Brooklyn extend over a considerable area on Long Island, and also in southern New Jersey. In this area there are many smaller ground water supplies. Of these the one at Camden, N. J., deserves special mention. The water is lifted by compressed air, from wells extending over a considerable area and forwarded to one central pumping station. The air is compressed at this station, and is carried to the wells in wrought iron pipes. By this means an unusually large amount of water is handled at one station. There is an economy in labor, but the use of coal is not reduced, as the compressed air is not an efficient means of transmitting power.

The compressed air method of pumping is extensively used for raising ground water to the surface of the ground. It is used both where the wells are far removed from the pumping station, and where the water level in the wells is too far below the pumps to permit of its being taken directly by them.

In Camden (pop. 94,538), the wells are close to the Delaware River, and the amount of water obtainable is increased by taking river water over the surface of some of the ground about the wells. This water filters through the sand slowly and is well purified. This method of adding to the yield of wells is used at some places in Germany and France.

Memphis, Tenn. (pop. 131,105), is probably the largest city in the United States supplied entirely with water drawn from sand and gravel deposits. In this case the water-bearing area is several hundred feet below the surface and is below a clay layer.

Lowell, Mass. (pop. 106,294), has had three stations draining different areas of glacial drift, but at present the whole supply is maintained from two of them. Of these the one yielding the larger quantity of water is on the bank of the Merrimack River.

Filter galleries, or excavations in sandy materials near river banks, have been used in the past. At present tubular wells are usually preferred. It makes no difference with the quality of the water which is used. The wells allow the water to be drawn at a lower level, and this tends to the drainage of a greater area, thereby securing a larger quantity of water at one station.

Formerly many towns and cities were supplied with ground water from gravel deposits which are now supplied with water from other sources. The change has usually been made because the ground water works were not able to supply the increasing quantities of water required by rapidly growing populations. To a certain point, limited by the area of collecting surface and storage capacity in the sand, the quantity of water obtained can be increased, but this limit is reached sooner or later.

When the supply is derived in part from infiltration from a neighboring river, there is often or usually a gradual decrease in the amount of water available. This is because the pores in the filtering material become filled with the sediment of the river water which enters them. In some torrential streams the filtering surface is renewed from time to time, but usually this does not occur, and there is no way of renewing the source when its capacity is reduced in this way.

Wells in Sandstone Rock. Wells in porous sandstone

rock are often used where such rock exists. The Marshall and Potsdam sandstones underlying parts of Michigan; Illinois, Wisconsin, and Minnesota, are used extensively for supplying towns and small cities. Jackson, Mich. (pop. 31,433), is one of the largest cities so supplied.

The method of driving the wells differs from that of driving wells in sand, but the collection, storage, and flow of water are precisely the same. The cementing material which binds what would otherwise be loose sand into a solid rock often seems to offer but little resistance to the flow of water, and the sandstone, for water supply purposes, acts as so much sand would do.

Most of the sand deposits of the country are not practically available for water supply purposes because the grains of sand are too small, and the flow of water through them is too slow. It is only the coarse-grain sands that are practically available. In the same way there is a great difference in sandstones. Only the coarse-grained ones yield water freely, and some of the most extensive formations are not water bearing.

Water drawn from sandstone is always well filtered.

The amount of water which could be obtained from sandstone formations in some parts of the country with sufficiently extended works is very great indeed, and the water is of the greatest value for small supplies. For large supplies, the limited amount that can usually be drawn regularly by one pumping station is a serious obstacle. The multiplication of small, scattered pumping stations may often involve a larger outlay than the cost of securing good water in other ways.

It very rarely happens that over 3,000,000 gallons of water per day are handled from one pumping station, either from sand or from sandstone. The capacities of by far the greater number of such sources will be fully reached with much lower drafts, often with as little as 1,000,000 gallons per day, or even less.

Limestone Water. Bethlehem, Pa., is not a large city but it is an old one, and it was one of the first in this country to have a public water supply. This supply was from a spring coming through a crevice in the limestone rock. The spring is one of the outlets for the drainage of a considerable area near the city and higher than it. The underground flow of the water is not through the porous rock, for limestone is not porous. It is through fissures or passages. These are called caverns if they are large enough and are accessible. Such fissures or passages exist in most limestone formations. They are the natural seams or cracks enlarged by the gradual solution and removal of the rock by the passing water. Limestone is the only common rock that is soluble in this way, and, for water supply purposes, limestone formations must be distinguished from all others.

As the crevices may be, and often are, continuous for many miles, and as they are large enough so that large quantities of water can flow through them, it often happens that quantities of water, many times greater than are ever obtainable from sandstone, are to be secured from limestone. On the other hand, as limestone is not porous, except for the open passages, there is but little storage in a limestone country. That is to say, there is but little ability to hold the abundant winter flows to

maintain the supply through summer droughts. The difference between limestone and sandstone in this respect is striking. While much more water is frequently available at one point in limestone, the amount is subject to greater fluctuations, and the supply may fall short when most needed.

San Antonio, Texas (pop. 96,614), is supplied with water from limestone springs flowing in great volume. For a long time, until the city grew to be too large, the flow was sufficient to furnish water power on a moderate fall just below the springs, to pump the water required to supply the city to an elevated reservoir.

Wells drilled in limestone rock, if they strike large and extended passages, often yield water freely. Such wells may drain the material over the limestone for miles. If that material happens to be clayey or impervious, the yield will be less.

Indianapolis was at one time supplied from wells in limestone, and Winnipeg in Canada is still so supplied. In both cases the amounts obtainable were too small to allow continued dependence on these supplies.

Limestone waters are not well filtered. To a large extent they are subject to pollution from the entrance of whatever polluting materials there may be on the tributary areas. Paris, France, partially supplied with limestone water, has been much troubled by such pollution. The water was for many years believed to be pure, but more recent investigations have made it clear that at least a considerable part of the excessive amount of typhoid fever long prevalent in the French capital has been caused by this water.

Vienna has been more fortunate, but this is because the catchment area supplying the wonderful "Kaiser Brunnen," and the other limestone sources largely supplying the city, are all in the high mountains, where there is scarcely any population or pollution. For these supplies the storage question is supplied in a most unusual way, namely, by means of ice and snow. The high mountains are snow-capped, and the melting snow in summer replenishes the springs, so that the summer discharges are greater than the winter ones.

In general, limestone supplies are of inferior sanitary quality. Typhoid fever has been caused by their use rather frequently. Such cases have been investigated repeatedly and thoroughly in Germany, Switzerland, France, and England, and less frequently in the United States.

Sandstones and limestones are the only rocks important as sources of underground water. Artesian wells are sometimes sunk in other rocks, and occasionally water is secured. This happens where the well strikes an open seam, which serves as a passageway for water entering it from pervious overlying material. Wells of this kind seldom yield enough water for public supplies, even in small towns, though supplies for private residences, small hotels, and mills, are not infrequently obtained in this way.

Hardness of Ground Waters. Ground waters are apt to be hard; that is to say, they contain large amounts of lime and magnesia in solution. This tends to make them less desirable for public water supplies. Frequently, however, this is not a controlling consideration, although always an important one.

Two conditions must be present to make a ground water hard. First, the material through which the water passes, or some of it, must contain the hardness-producing material, and second, the conditions must be favorable for dissolving it. The latter practically means that carbonic acid must be present.

The waters from the gravels at Brooklyn and Camden and Lowell are soft, because the gravels contain but little lime, and that little is not in a soluble condition. Sand and gravel free from lime are common in New England, parts of New York and New Jersey, and generally along the Atlantic coast to the southward.

On the other hand, the sands and gravels of central New York, and westward to Minnesota and beyond, contain lime in considerable quantities, and waters drawn from them are hard.

Different waters drawn from lime-containing materials vary greatly in hardness. Generally the hardness of the water does not depend upon the amount of lime in the material through which it has passed, but upon the power of the water to dissolve the lime. If any lime at all is present in form to be dissolved, there is pretty sure to be enough of it to render the water extremely hard if carbonic acid is present in the water to take it up.

Rain water contains but little carbonic acid, and has therefore but little power of dissolving lime, and so of becoming hard while passing calcareous materials. The principal source of the carbonic acid required to enable the water to dissolve lime is the soil. The soil contains organic matter in the shape of roots, humus, etc. Some

of these matters are decaying and becoming oxidized with the formation of carbonic acid. The rain falls on the soil, penetrates it, and becomes charged with carbonic acid. Then it passes to the calcareous sand or other material below, and lime from it is dissolved to the extent of the dissolving power of the carbonic acid.

The hardness of the water therefore depends more upon the richness or fertility of the soil upon the catchment area than upon the amount of lime in the various materials through which the water flows, provided of course that there is some substantial amount of lime to be taken up where conditions permit.

The water supply of Vienna is for this reason comparatively soft, notwithstanding that it comes entirely from limestone rocks. The gathering ground is barren and sterile, and the water never gets the carbonic acid needed to dissolve a large amount of lime. In a sand-hill region, where the sand is calcareous, the ground water will be only moderately hard, because of the barrenness of the soil. With better soil, the water will be harder, until with an extremely rich, fertile soil over limestone, as at Winnipeg, Canada, water of the very greatest hardness is found.

Iron in Ground Water. After hardness there is no question of greater importance in considering the quality of ground waters than the presence of iron. Iron is very widely distributed, and practically all the sands, gravels, soils, and rocks with which water comes in contact, from the time it strikes the soil as rain water until it emerges to the spring or well, contain it. Sometimes the

conditions are not such as to result in the solution of the iron, but frequently an objectionable amount of it is taken into solution.

When iron is present in water it supports the growth of crenothrix, an organism which grows in the pipes and which is extremely troublesome. And it further separates, forming a red precipitate which is offensive in appearance and is dirty in tanks and wherever the water is stored. Water containing iron also discolors and spoils linen and other fabrics washed in it.

The solution of iron from the soil is brought about by organic matter. This takes oxygen away from the iron of the soil, reducing it from the ferric to the ferrous state. In the ferrous state the iron is soluble in water containing carbonic acid, and trouble from iron is always to be expected where there is an excess of organic matter in the material through which the water passes.

The organic matter may come with the water itself, in case of seepage from a dirty and polluted river; or it may be present in the soil. Rain water does not contain much organic matter, but the soil on which it falls is usually rich in it. In a well drained, pervious soil the oxygen from the air circulates in the pores of the soil and furnishes what is required by the organic matter. Iron will not be dissolved under these conditions, even in presence of large amounts of organic matter. But if the air supply is cut off, as, for instance, in case the pores of the soil are filled with water by flooding or saturation, the solution of iron is sure to take place.

Iron can be removed from ground water by a suitable

method of purification, and such removal has made possible the utilization of many valuable sources of supply that otherwise could not have been used.

The ground waters of northern Germany very commonly contain iron. Twenty years ago Berlin put down many wells and works for securing ground water, the conditions in the neighborhood of that city being exceptionally favorable. But after a short period of use the wells were abandoned because of the iron in the water which made the water objectionable. At that time it was not known how to remove the iron. Afterward methods of iron removal were discovered and used in other German cities, and finally in the last years the old Berlin well water supplies have been gradually brought back into service and extended, but this time with the complete artificial removal of the iron from the water. And this water is gradually supplanting the filtered river water which otherwise has been used to supply the city.

All these German iron-containing waters are from deposits of silicious sand, in a general way, similar to that from which the Brooklyn, Lowell, and Camden supplies are obtained.

Of the American ground water supplies, a considerable proportion suffer from iron, and a number of works for iron removal are in use, though not for the larger supplies. As far as known, the Camden supply has not suffered from iron. At Lowell, the iron is more or less troublesome. The Brooklyn wells are very variable, according to location. Some are free from iron. Others have so much that the unmixed water from individual wells would not be usable. But when it is all mixed in

the conduit, including large amounts of surface water, the iron is not present in large enough amounts to be very troublesome. It is noticed, however, and is an undesirable element in the supply.

Superior, Wis., Far Rockaway, N. Y., and Asbury Park, N. J., are among the most important and best known places in the United States, where the iron in ground water supplies has compelled the construction of works for its removal.

Manganese also occurs in ground waters occasionally. Manganese is a metal similar in many ways to iron, and is the basis of the "spiegeleisen," used in making steel. It is less widely distributed in nature than iron. When it is present in the soil it dissolves under the same conditions that lead to the solution of iron. It is equally troublesome to the users of the water, and is much more difficult to remove by artificial purification.

Breslau, Germany, has suffered from manganese as well as from iron, and part of the recently constructed ground water supply works have been abandoned because of it.

As far as known manganese has not been troublesome in any very large public supply in America, but it has proved most objectionable in a few small ones, and in some mill supplies.

It is much more difficult to test water for manganese than for iron, and but few chemists have looked for it adequately. It is therefore possible that full investigation will show a wider distribution of manganese in American waters than is now recognized, and that some

troubles with water, the causes of which are not now understood, may be attributed to this metal.

Sea Water in Ground Water Supplies. Many important supplies are drawn from wells near the ocean. The Brooklyn supply is so located, also the Far Rockaway supply, and the supplies for Staten Island and Asbury Park, and many small places along the New Jersey coast. The supplies of The Hague and Amsterdam in Holland are also obtained close to the coast. In all these cases the presence of sea water in the wells is an important matter. In many cases trouble has already been experienced. In others there would be trouble if care was not exercised to prevent it.

The admixture of even a small proportion of sea water renders the water hard and salty and undesirable for domestic use. The magnesium chloride also renders such water unsuitable for use in boilers. The passage of sea water through the sand between the sea and the wells does not remove the salt of the sea water, or even reduce it in the slightest degree.

In most of the supplies above mentioned the fresh water resulting from the rainfall upon the sandy areas near the coast naturally reaches the sea through the sand below the water level. Its discharge accounts for the springs and quicksands often noticed on the beach at low tide. Little or none of this water naturally comes to the surface of the ground before reaching the sea.

It is a difficult matter to draw to wells or galleries all the fresh water that would otherwise flow to the ocean,

without at the same time drawing some salt water to the wells. In fact, it is not possible to do this perfectly. It is an interesting and difficult problem to so arrange and operate the works as to get the maximum quantity of fresh water without drawing sea water.

The problem is complicated by a fairly strong tendency, due to the difference in specific gravity, for sea water to flow back under the land in the sand below the surface, when the water level at a distance back from the shore is lowered by drawing upon the wells; and this underflow of salt water may take place while there is still a surface flow of fresh water to the ocean.

When sea water passes back under the wells in this manner it is sure to become mixed with the fresh water above it in the wells sooner or later. The process of mixing is constantly taking place from the first moment that sea water begins to flow into the land, and by the time that sea water is first detected in the wells, large amounts of sea water may be in the sand below them, and it may then be a slow, hard process to operate the wells so as to avoid drawing sea water.

It is clear that for a time an amount of fresh water largely in excess of the yield that can be permanently maintained can be drawn from such wells, the excess amount being taken from the sand, and its space being gradually taken by salt water. For this reason the amount of water which can be permanently maintained from such works is much more difficult to determine, and in fact can only be determined by experience extending

over a far longer period than is required to establish the yield of wells not so situated.

This sea water question has been more thoroughly and scientifically studied in Holland than elsewhere. The Dutch literature upon this subject is most important, and many of the methods of studying conditions and of regulating the supply that are there used may be adopted elsewhere with advantage.

CHAPTER VI.

ON THE ACTION OF WATER ON IRON PIPES AND THE EFFECT THEREOF ON THE QUALITY OF THE WATER.

IT is well known that nearly all waters attack iron pipes, corroding them and forming tubercles on the inner surface. The rates at which this corrosion and tuberculation take place with different waters and different kinds of pipe have been studied by many engineers at length. It has been studied almost entirely from the point of view of the reduction of carrying capacity of the pipe, and hardly at all from the standpoint of the effect upon the quality of the water. The latter seems to be a matter of considerable importance, however.

The way that the process of tuberculation goes forward seems to be something like this: The water flowing, at times slowly, and carrying matters in suspension, deposits some of these suspended matters on the lower half of the pipe. This deposit usually contains a considerable amount of organic matter.

The iron pipe is coated with tar or asphalt. If this coating were perfect and complete, the deposit would not come in contact with the iron at any point. But there are always blow-holes or other minute openings in the coating, and it is through these that the iron is first reached.

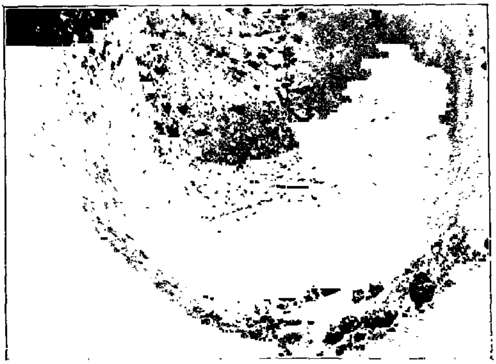
The organic matters in the deposit over the iron are in a state of decomposition; that is to say, they are rotting. This results in the generation of carbonic acid. The carbonic acid acts on the iron through the openings in the pipe coating. It takes some of this iron into solution as ferrous carbonate. The soluble ferrous carbonate diffuses through the water, penetrating the deposit under which it is formed, and reaching the upper surface of it, where it comes in contact with the water flowing in the pipe. A part of the iron mingles with the water in the pipe and goes forward with it. Another part, becoming oxidized by the oxygen in the flowing water, is transformed to the insoluble ferric condition and remains at the surface of the deposit.

The iron precipitated in this way acts as a coagulant. It coagulates some of the organic matter in the flowing water at the point where the iron is precipitated. It binds the organic matter so precipitated, and that previously deposited, into a firm, compact, but porous mass, and this mass is the beginning of a tubercle.

The organic matter precipitated by the iron at the surface of the tubercle is so much fuel added to the flame of decomposition, and the carbonic acid resulting from it leads to the solution of further quantities of iron. In this way the process becomes a continuous one.

The circulation of the liquid through the tubercles, taking the carbonic acid to the iron and bringing the iron to the surface, is very slow, and many years may elapse before the tubercle reaches the height of an inch.

Tuberculation is practically universal in cast iron water pipes, but some waters cause the action to go for-



Tubercles Growing in Iron Water-pipes.
Courtesy of Prof. Gardner S. Williams.

ward much more rapidly than others. Tuberculation starts much more freely, and progresses more rapidly, in waters from rivers or reservoirs containing suspended organic matters. It is less troublesome with filtered waters and with lake waters relatively free from such suspended matters. Pipes carrying river waters containing much inorganic sediment, that is to say, clay and silt, and having but little organic sediment, are less likely to become tuberculated than those carrying waters with organic sediment.

The difference between the action of raw water and filtered water upon pipes is very striking in the piping about filter plants. The tubercles in the raw water pipes are found to be much more numerous and larger than those in the filtered water pipes.

The character of the tar or asphalt pipe coating also has a great deal to do with tuberculation. The coal-tar dip is still used for cast-iron pipe and sometimes for steel pipe, and on the whole has stood the test of time as well or better than many of the improved coatings that have often replaced it.

The cement lined pipes, extensively used years ago, and now abandoned in water works practice because of defects in other particulars, were not subject to tuberculation, and had this distinct advantage over the cast iron pipes which have displaced them.

The effect of tuberculation in increasing the frictional resistance of water in pipes, or, what is the same thing, of decreasing the flow through them, is well known. It is common to find that twice as much head is required to carry a given quantity of water through a pipe after twenty years of use as when the pipe was new.

Pipe scrapers have been sometimes used to remove tubercles. They consist of appliances driven by the water pressure through the pipes with arrangements to scrape off the tubercles. Scraping in this way has the effect of restoring to a considerable extent the original carrying capacity of the pipe. The process, to remain effective, must be repeated at intervals, and when so repeated it has the effect of removing a large part of the tar coating and leaving the iron of the pipe exposed to the action of the water to a much greater extent than would have been the case without scraping.

The iron that is oxidized and dissolved as a result of the process of tuberculation is, in considerable part, precipitated at the surface of the tubercles, and it forms the cementing material which makes them possible. But only a part of the iron is thus precipitated; the rest goes forward with the flowing water. At first it is in a state of solution, but the dissolved oxygen in the water oxidizes it slowly to the ferric or insoluble state.

If the water contains much organic matter in solution this may prevent the precipitation of the iron. In this case it increases the color of the water. It is able to do this only where the amount of iron in proportion to the organic matter is comparatively small. This is usually the case with dirty river and reservoir waters. If there is not sufficient organic matter in the water to hold the iron in solution, it will separate out after oxidation and will deposit where the flow in the pipes is slow. This is usually the case with filtered water and other waters of organic purity.

That part of the water which goes through the water-

backs of the kitchen stoves to the hot-water tanks is particularly likely to have its iron separated, and the iron so separated usually accumulates on the bottoms of the hot-water tanks. The iron separating from the water in this way is not likely to be drawn at all times. It is far more likely to accumulate in pipes and tanks for days or even for weeks, until sometime, with an unusually rapid draft of water or other disturbance, perhaps on washing-day, the iron which has accumulated for days or weeks is all flushed out in a limited quantity of water. Then the superintendent of the water works hears from it.

This intermittent appearance of iron is one of the characteristic features of iron troubles from ground water, and the presence of iron is much more objectionable to the takers of the water than it would be if it was more uniformly distributed through the water.

The solution and subsequent precipitation of iron in this way seems to be more or less universal in connection with iron water pipes. The tendency of this action is to make a surface water behave like a ground water naturally containing iron, and all the disagreeable features of an iron-containing ground water may be produced in greater or less degree as a result of these actions.

Where water is taken from a source that is recognized to be dirty, as, for instance, from a turbid river or from a reservoir with vegetable growths, the public is pretty sure to take these phenomena as representing a part of the natural dirtiness of the source. There are cases where the uncleanness popularly attributed to the water

of the source is really attributable in greater measure to the iron taken up from the pipes.

For this reason it seldom happens that the action of the iron pipes in increasing the dirty appearance of the water is recognized as long as the source of supply has a bad reputation. When a filter plant is installed, or clean water from a new source is secured in place of a dirty one, then the effect of the iron commences to be noticed and to receive serious attention. It is found that water leaving a filter plant or entering the pipes from a new reservoir, is bright, colorless, and free from iron. As drawn from the taps to the consumers it is discolored and comes out a milky yellow or reddish, according to the amount of iron present. This color comes intermittently, and between the dirty spells there are times when clean water is drawn. The people get used to the appearance of clean water, and quickly notice the difference when the iron comes, and they are troubled by it. Often they believe that the filter has gone wrong, or some unreported source of pollution is reaching the water.

Sometimes the matter is aggravated by a softening by chemical action and loosening of old deposits in the pipes which follows a change in the character of the water supply. When this is the case, repeated and adequate flushings of the pipe will considerably improve the situation.

To make flushing effective it is necessary to shut off all side pipes and open the hydrants at the end of each line of pipe, so as to produce through that line for a few minutes a velocity many times greater than any that is possible in ordinary use.

Flushing must be done in this way to be effective, and opening hydrants here and there throughout a city, without closing the gates necessary to concentrate the flow, simply has the effect of stirring up the old deposits in the pipe, and of mixing them with the water, and of producing unnecessarily bad water without effectively removing the source of trouble.

This deterioration of water as a result of contact with iron pipes, and especially of old pipes containing large numbers of growing tubercles, is one of the most troublesome ones in connection with securing clean waters and of supplying them through pipes long used for carrying dirty water.

The troubles resulting from it are important, even though not of equal importance to sanitary quality or to turbidity and color. Water is never less wholesome because of iron, but it is less attractive in appearance, and the difference is clearly noticed by the public.

The tubercles that grow in water pipes are very good friends to the men who sell spring water. They also do a great deal to make possible the business of supplying domestic filters.

Domestic filters are not in general a very sure means of removing disease-producing qualities from polluted waters. There are too many uncertainties connected with their operation to make them reliable in this respect. But the iron that comes from the pipes is very easily removed by such filters, and good domestic filters furnish the most convenient and satisfactory means of removing such deposits from water that is otherwise good.

Probably if new pipes should be provided in place of the old ones, when clean water is secured at the source; and if better coatings could be used, relatively little trouble would be experienced from iron. But the old water pipes are in use, and they represent large investments and cannot be changed for a matter of secondary importance.

It is to be hoped that a study of this subject and a recognition of its importance will result in time in the use of better pipe-coatings, or possibly in the use of pipes presenting to the water some surface which is not subject to tuberculation.

In the meantime, managing the situation by flushing out such old deposits as can be flushed out, by explaining the action of the tubercles to those citizens who are sure that the water is bad when it is only temporarily discolored, and generally keeping the public good-natured, calls for the greatest skill and tact on the part of the water works superintendent.

CHAPTER VII.

RED-WATER TROUBLES.

THE term "Red-water Troubles" has come to be applied to conditions of the general character described in the preceding chapter, where the amount of iron in the water drawn from the taps of the consumers has increased to a point to be generally objectionable.

Red-water troubles are most prevalent with very soft, clean waters. They are less frequent with harder waters.

The pipes employed to take water from the street mains and through the houses have been found to play a larger part in the red-water problem than the street mains. Although the distance that the water passes through these service and plumbing pipes is short, it frequently happens that more iron is taken up from them in a few feet than from the miles of pipes in the streets through which it passed before reaching them. The red-water troubles result from the total amount of iron in the water drawn; and it makes no difference whether it came from the street pipes or from the plumbing.

It often happens that a little iron is taken up from the street pipes, but not enough to be noticeable by itself. With the added amount from the service pipes the total is increased until it is noticeable, and the amount taken

from the street pipes is thus a contributor to the final result, although insufficient alone to produce it.

The corrosion of iron in the hot-water system, other things being equal, is many times more rapid than in the cold-water system, and it takes place not only in the pipes, but also in the heaters, hot-water tanks and wherever water meets iron in the hot-water system. Red-water troubles are therefore much more common and more conspicuous in the hot water than in the cold water. Frequently they are confined to the hot water.

Red-water troubles are often found in some houses on a street but not in others. The difference in rapidity with which pipes in different houses corrode is often strikingly great and difficult to explain.

Formerly lead pipes were used for service and plumbing pipes more than at present. Their use has been discontinued, in many cases because it has been found that certain soft waters attack the lead slowly, taking a little of it into solution, and tending to produce lead poisoning among those who use the water. Generally speaking, the waters that are soft enough and have corrosive power enough to attack lead are also the waters which corrode iron, and with which red-water troubles are experienced.

Various kinds of pipe have been used to take the place of lead pipe, but galvanized wrought-iron pipe has been used more than any other. The zinc of the galvanizing is intended to protect the iron from corrosion, and actually it does so to a certain extent; but the actions that would dissolve the iron also dissolve the zinc, and sooner or later the protective zinc disappears in whole or in part and the corrosion of the iron goes forward.

Steel pipe has largely replaced wrought iron in the last decade, and in keen business competition the quality of the pipe has been reduced, and inadequate methods of galvanizing have been used, so that much of the pipe actually sold has been of a kind to be more easily corroded than the well-galvanized wrought-iron pipe formerly used and still to be obtained at an increased price.

Poor and imperfectly galvanized pipe has been one of the most potent causes of red-water troubles, as is demonstrated by the fact that in almost every community where red-water troubles exist many individual houses will be found using galvanized-iron pipe where no trouble is experienced. Frequently the older houses have given less trouble because the pipe was of more resistant quality when they were built, while the newer ones have suffered most.

Since the discussion of red-water troubles in the last years there has been renewed effort to secure a better grade of pipe, and this is no doubt being gradually accomplished.

Anything that increases the tendency to corrosive action of the water increases the likelihood of red-water troubles. The chemical treatment of water used to aid in the removal of color, turbidity and other matters has been often carried out in such a way that the water supplied was more corrosive than the water would have been without the treatment. Apparently with very soft water and a short period of coagulation the chemical reaction taking place between the coagulant and the lime in the water does not have time to be completed before the water goes to the filters, and the filtered water

acts as if it still contained some slight undecomposed residue of the coagulant with its corrosive powers, even though the water carries more than enough lime to complete the reaction.

It is not, however, necessary to accept this view to account for the increased corrosive action of the coagulated water. The reduced alkalinity and the increased carbonic acid resulting from the coagulation both facilitate corrosion; and the change in the water in these respects as a result of the coagulation of a very soft and highly colored water would be sufficient to make an appreciable difference in the behavior of the water in the pipes.

Red-water troubles are preventable. It may not always be feasible to apply remedies sufficient to provide a complete cure, but they can always be reduced to relatively unimportant proportions.

Local Remedies. Brass pipes and copper-storage tanks should be used exclusively in hot-water systems where there is a tendency to red water, and the area of the exposed iron in the heaters should be reduced as much as possible. These simple measures will prevent red-water troubles in the hot-water system in nearly all cases. The increased cost of using brass in new houses as compared with galvanized-steel pipe is not as great as might be supposed, because the brass pipe is smoother and carries more water, even when new, and is not subject to corrosion with the accompanying reduction in carrying capacity when old. Brass pipe may therefore be one or two sizes smaller without sacrifice of capacity. It is not necessary to use any pipe more than half an inch in

diameter in a brass hot-water system of an ordinary residence.

For the cold-water system galvanized pipe may be used, but it should be from a responsible manufacturer and protected by an adequate coating of zinc, and should be thoroughly inspected to insure its quality.

Generally speaking, the red-water troubles are worst in houses where the water is heated very hot. We have examples of this in apartment houses, where the water is heated in special heaters in the cellar and in houses where it is heated in the furnace. A temperature of 140° is sufficient for all ordinary uses of hot water, and to exceed this only invites trouble. Where the water is heated by gas it is possible to regulate the temperature of the hot water.

It has been suggested that passing the heated water into an open tank at the top of the house and delivering the supply to the faucets by gravity from this tank would reduce corrosion by permitting some of the dissolved oxygen to escape. Under some conditions this might be worth doing.

These local remedies will serve to correct the worst of the red-water troubles.

General Treatment. In addition, it may be desirable to employ some general remedy, consisting of a special chemical treatment of the water to reduce its corrosive power.

Quicklime is probably the most efficient all-round material to be added to water for this purpose. Its use increases the alkalinity and reduces the free carbonic acid. It increases slightly the hardness of the water;

but it may be noted that the treatment is only desirable in the case of extremely soft waters; and in these cases the relatively slight increase in hardness, due to the addition of the small required amount of lime, may not be objectionable.

Calcium carbonate, applied in the form of an insoluble powder, has been used in England to harden very soft moorland waters, and to reduce their corrosive power, especially with reference to bad service pipes. It takes twice as much calcium carbonate to take up a given amount of carbonic acid, and the substance being an insoluble powder is not as conveniently and easily applied as the soluble quicklime.

Soda ash has been employed to increase alkalinity and reduce carbonic acid, and it does this without hardening the water; but it is more expensive than lime and it also seems to be less efficient.

The use of the lime treatment to reduce the corrosive powers of waters is not confined to waters that have been coagulated. Coagulation only increases slightly the previously existing tendencies, and these tendencies are frequently so great as to warrant corrective treatment even where no coagulant is applied. Mr. George C. Whipple [1] has suggested the advisability of the use of lime with all exceedingly soft waters to decrease the corrosion of the pipes and improve the physical character of the water that can be drawn from the house faucets.

Journal of the New England Water Works Association, Vol. 27, p. 193.

CHAPTER VIII.

DEVELOPMENT OF WATER PURIFICATION IN AMERICA.

The filtration of river waters to remove sediment and turbidity and other impurities has been practised in Europe for many years. The first serious American effort in this direction was made by the city of St. Louis in 1866, when the late J. P. Kirkwood, a civil engineer, was sent to Europe with instructions to study the art and apply it to St. Louis.

Mr. Kirkwood made a report upon this subject, and a general plan for works for St. Louis based upon this study. This report was most remarkable for the insight shown into the conditions of success with European waters, and it will always remain as a singularly accurate statement of the conditions of the art as they existed at that time.

Kirkwood's plan for filtering the St. Louis water was not adopted. Possibly the cost was too great and the benefits of purification too little understood at that time; but there is some reason for supposing that tests made on a small scale, the results of which were not made public, served to show the inadequacy of the proposed plan. However that may be, we now know that the plan would not have given success, and that no plan

based on European experience could have done so. For among the filters of Europe there was not one that received water resembling even remotely the Mississippi River at St. Louis, or that was capable of treating such water.

Although Kirkwood's design for St. Louis was never carried out, several filters were built by other cities as a result of his work and report. From his plans a filter was built for Poughkeepsie, N. Y. There the conditions were sufficiently like those of European filters; and the plant was the first, and by far the most successful, of the early water purification plants in this country. Afterward a number of small but successful plants were built upon similar lines. Among them were the filters at Hudson and at West Point, N. Y. (both near Poughkeepsie), and at St. Johnsbury, Vt.

In other cases success was not attained. Lowell, Columbus, Toledo, and other cities also copied the Poughkeepsie filters more or less closely but without corresponding success. These failures were no doubt due in some cases to the failure to provide adequate filtering area, and to modifications of the design which did not prove to be beneficial. And in other cases they were due, or partly due, to the fact that the water carried more suspended matter, and this affected the process to such an extent that the general method was not applicable.

Soon after this the late Professor William Ripley Nichols of Boston became interested in filtration. He made experiments with it, talked of its application to the particular problems with which he had to do, and wrote an uncommonly interesting report upon the subject of

water purification based, like Kirkwood's, upon European experience.

This report led to an experimental trial by the late A. Fteley, then engineer of the Boston water works. Other trials were made at Louisville and elsewhere. These trials, on the whole, were not encouraging, and did not lead to practical applications of the method.

About 1884 the beginnings of a new method of filtration, destined to play a large part in water purification, made their appearance. The process was patented by the late J. W. Hyatt, and the late Professor Albert R. Leeds was largely interested in the early development of the invention.

The essential and characteristic features of this method were the addition of a coagulant or chemical precipitant to the water, and afterward passing it through a sand layer so arranged that it could be mechanically washed by a reverse current of water, aided sometimes by other appliances. These features are characteristic, and have been the distinctive features of mechanical filtration, as it is called, to the present day.

This method met with some successes, and in the decade that followed quite a number of plants were installed. These were divided between supplies for small cities, and supplies for paper mills. Paper mills require large quantities of clean water, and they have been among the earliest and best patrons of those who had methods of purifying water.

The Massachusetts State Board of Health commenced to investigate the purification of sewage and water in

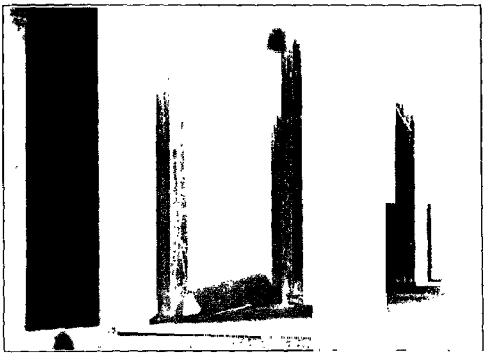
1887. At first the purification of sewage received most attention, but about 1890 the study of water purification was taken up energetically. And this experimental work did a great deal to develop the art of water purification in America.

In carrying out these investigations Merrimack River water only was used. This water, which was used by the city of Lawrence at the time, contained a great deal of sewage, and caused much typhoid fever among those who used it. It was also somewhat colored, but was not subject to much turbidity. It was in a general way much the same kind of water that had been successfully filtered in Europe for the supply of such cities as London, Berlin, etc.

These experiments were carried out at Lawrence, under the direction of Mr. Hiram F. Mills, with at first the writer, and afterward Mr. George W. Fuller, and still later Mr. H. W. Clark, in direct charge, and with the advice of the late Professor Thomas M. Drown, and of Professor William T. Sedgwick. They served to determine in a practical way the nature of the processes that were investigated, and to show the conditions of success with them as far as they could be determined by small experiments; and the results obtained, which were most promising and were duly published, served to interest many people in water purification.

As a result of these experiments the city of Lawrence built a sand filter to purify its water supply. This was designed by Mr. Mills, following in a general way, but not in detail, European precedent, for it was based largely upon the results of the tests made, and in many

Interior of a Sand Filter at Toronto, showing layer of dirty sand removed by scraping.



Interior of covered pure-water reservoir at Watertown, N. Y.

ways it was quite different from any previous construction. This filter was put in service in 1893.

The Lawrence filter was the first filter built in America for the express purpose of reducing the death rate of the population supplied, and it accomplished this purpose in a most striking manner. Comparing the five years after it was in service, with five years before it was in use, there was a reduction of 79 per cent in the typhoid fever death rate, which had been excessive for many years. No less remarkable than this was the reduction in the general death rate from all causes of 10 per cent, namely from 22.4 to 19.9 per thousand living.

Following directly the success of the Lawrence filter, a number of other filters were constructed more or less like it, but none of them supplying as large a city as Lawrence.

Up to the year 1893 but little progress had been made in understanding the process of mechanical filtration, although many plants had been installed, mostly in the smaller cities and towns and in paper mills. The details of construction and operation had been developed to a considerable extent, but there was no adequate knowledge of what could be done in securing pure water, or how it could best be accomplished.

In that year Mr. Edmund B. Weston made some tests for the city of Providence, which indicated that very good work could be done by mechanical filters in purifying a sewage-polluted water. These tests were by no means all that could be desired, but they were important as being the first carefully conducted tests with that kind of filtration.

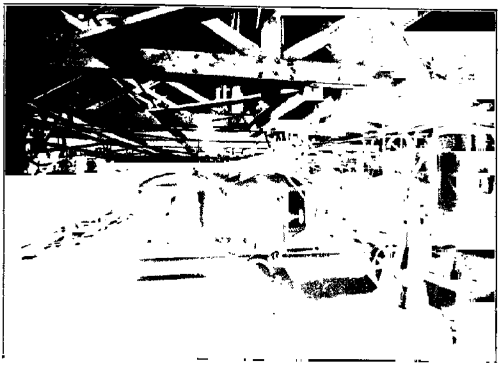
Meanwhile, the mechanical filters installed, though often giving relatively good service, were not by any means doing so uniformly. The conditions of success with them certainly were not understood. While excellent results were occasionally reached, the average work was at best mediocre, and there were conspicuous cases of failure to accomplish the desired results.

The practical and scientific basis for mechanical filtration may be said to date from the Louisville experiments of 1895–97. These were made under the direction of Mr. Charles Hermany, assisted by Mr. George W. Fuller, acting for the Louisville Water Company, and by several companies interested in the construction of mechanical filters.

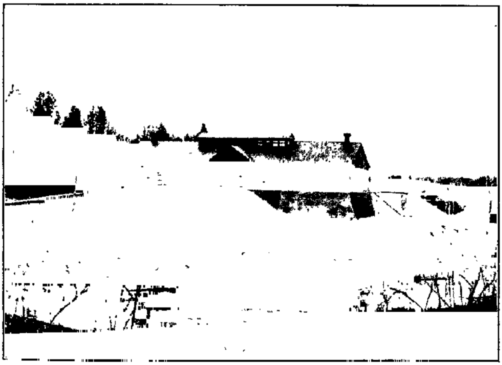
These experiments were made upon the Ohio River water, and this water was radically different in quality from the Merrimack River water which had been experimented upon at Lawrence, as well as from all the waters with which practical experience had been had in Europe.

The difference was principally in the matters carried in suspension, or in the turbidity. The Ohio River water carried varying amounts, and at times very large amounts, of clay in suspension. Some of the clay particles are much smaller in size than the bacteria, the smallest organisms, the removal of which has been regarded as important. So finely divided is some of this clay that it will hardly settle from the water at all.

The removal of this clay is important and necessary on its own account, for no water can be considered adequately purified and satisfactory for a public water supply while it contains any appreciable turbidity of this kind.



An early type of Mechanical Filter at Chattanooga, Tenn.
Courtesy of American Water Works and Guarantee Company.



The Little Falls Filters of the East Jersey Water Company.
Courtesy of Mr. G. W. Fuller.

Clay is also most important because when it is not removed its presence exerts an influence on many other things. Substances which would be readily removed by a given treatment in the absence of clay particles, may fail to respond to the treatment in the presence of such particles, and a treatment otherwise successful may fail when applied to a water containing them.

Now the Louisville experiments were the first to deal with this question of clay particles in a comprehensive way. The filtration proposed for St. Louis by Kirkwood, the filtration practiced in Europe, and the filtration studied at Lawrence were hopelessly inadequate for this business. The mechanical filters then in use in the United States, and those selected and designed for these tests were also inadequate, although they did embody to a large extent the ideas that were to prove successful, and were able, even at the outset, to accomplish a great deal.

As the tests progressed and the weaknesses of the various devices became apparent, modifications were made, and in this way at Louisville the first thoroughly successful method of treatment for this kind of water was reached.

The Louisville experiments brought mechanical filtration to a point where it was able to deal in an efficient and practical manner with many of the most difficult of American waters.

While the experiments were in progress at Louisville, others were undertaken by the city of Pittsburgh, and Cincinnati soon followed. Experiments were also made at Washington, at Superior, and at New Orleans, and elsewhere. And as a result of these, and the practical experiences with other waters by the men having to do

with them, and by a free exchange of the results of this experience between the different workers, data were rapidly collected as to the characters of different waters, and as to the ways in which they responded to different treatments; and in this way a basis was reached for laying out methods of treatment capable of purifying a great range of waters.

Now the range in the qualities of American waters is much greater than the range in the qualities of European waters. The excess of clay which has already been mentioned is a controlling element in a considerable portion of American river supplies.

With impounding reservoir supplies also there is a difference almost as important, due to the higher summer temperatures and the growth of organisms, giving rise to more seriously objectionable tastes and odors. Such growths are not often troublesome under European conditions.

Although the purification of water for the purpose of removing tastes and odors is highly important, it has received less study than the removal of clay. Nevertheless, something has been done with it. More study has been given to preventive measures than to corrective ones, although there are strong reasons for believing at this time that the latter are more effective.

The city of Reading, Pa., made some experiments in 1897, in this direction, and since that time plants based on the experimental results have been put in successful operation for cleaning the water from two impounding reservoirs, which were subject to algæ growths, and objectionable tastes and odors resulting therefrom.

The Ludlow Reservoir at Springfield, Mass., was one of the most notorious reservoirs for its tastes and odors. The city of Springfield and the State Board of Health made continued and elaborate experiments upon the treatment of this water, from 1900 to 1903. These experiments showed that the water could be successfully treated, though with rather elaborate appliances and at considerable cost.

Afterwards, in 1906, works for the purification of this water were installed. These works differed somewhat from anything that had been tested during the previous experiments, being simpler and cheaper. Only a partial purification was predicted and expected, but thus far the results have exceeded expectations.

One of the most important of recent developments in water purification has been the consideration of a partial softening of river waters in connection with the other processes necessary for their purification. The idea of the possibility of doing this is very old. Wanklyn's "Water Analysis," published in London in 1868, spoke at length of the possibility of doing this; but there were practical difficulties, and the process was not actually used at any place, and it has only been since about 1903 that the process has been taken up in a way to remove the difficulties.

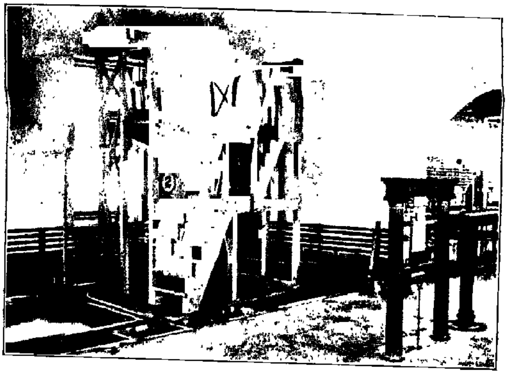
The development seems to have come about in this way. The coagulant most commonly used in mechanical filtration is sulphate of alumina or crude alum. Now, sulphate of iron, or copperas, is cheaper, and under some conditions fully as efficient as sulphate of alumina as a coagulant. With the iron it is necessary

to use lime, as without it precipitation is not sufficiently rapid and complete. Only a little lime, comparatively, is needed to throw down the iron. A considerably larger quantity will also throw down some of the lime naturally present in the water, together with the lime that is added. This is the old and well known Clark process for softening water, which is the basis of all water-softening methods.

In 1903, the iron and lime process of treating water was applied to the Mississippi River water supplied to St. Louis. In this case the water, after the chemical treatment, passed through settling basins but was not filtered. At Quincy, Ill., Lorain, Ohio, and other places it was applied as a preliminary to filtration. And it was soon found that when the amount of lime was increased, accidentally or otherwise, the resulting effluent was often softer than the river water. And when this was found it naturally led to the regular use of more lime and perhaps of less iron. In this way a substantial amount of softening was effected, at St. Louis and elsewhere, by the iron and lime process.

The matter was investigated by an exhaustive series of experiments at Columbus, Ohio, and the process was developed with a view to a combined coagulation and softening treatment prior to filtration. Works have since been built upon this principle and successfully operated at Columbus and at several other cities.

The use of partial softening brought about in this way does not greatly increase the cost over that of the treatments otherwise necessary for purification. It is even possible that with some river waters the process may be



Coagulating Devices at Watertown, N. Y.

Covered coagulating basins and mechanical filters in course of construction at Watertown, N. Y.

actually cheapened. If this result is secured it will be by making use of the magnesia of the water to do a part of the work otherwise accomplished by alumina or iron. This will not always be possible, but even when it is not, the advantage of soft water to a city is so great that large expenditures can well be made to secure it where the natural supply is hard.

While these advances have been made in the knowledge of the processes of purification, and of the means of carrying them out with success, an almost equal advance has been made in the materials of construction of mechanical filters and in their detailed arrangements.

The Hyatt patent, the underlying patent on mechanical filters, expired in February, 1901. After that the field was open. All other patents related to details; and no one of them, nor even any combination of them, could serve to control the field of filter construction.

From that day rapid advances were made. The designs for the Louisville filters, which appeared in 1900, were important as marking the beginning of a rapid advance. Reinforced concrete was substituted for the wood and iron constructions previously used. The Little Falls filters, treating the supply of the East Jersey Water Company, were put in service in September, 1902, and were the first filters to be actually used on the newer lines. These filters were also equipped with appliances for the better and more certain control of coagulants and were far better in other ways than any before constructed.

The use of larger coagulating basins to allow the chemical changes to become complete before the water passed to the filters was early introduced at a number of

Missouri River points, especially at the works owned by the American Water Works and Guarantee Company, at East St. Louis, Ill., and at St. Joseph, Mo.

The use of cement blocks for the bottoms of the filters, containing the necessary channels for the effluent and wash water, in place of the metal structures previously used, was introduced at the filters of the Hackensack Water Company, built in 1904, and is also used with modifications at Columbus, New Orleans, and elsewhere.

While these rapid and revolutionary developments in mechanical filters have been taking place, sand filters, following European precedent, have been installed in many places where the conditions have been suitable and in a few places where they were not, and developments with them also have taken place.

Following the Lawrence filter, the first large installation was at Albany, put in service in 1899. These filters were covered by masonry vaulting as a protection from frost, which had interfered more or less with the winter operation at Poughkeepsie and at Lawrence. Such covers had long been used in Germany for the same purpose, and also at a few small American plants.

The Albany filters received water from the Hudson River a few miles below the outlets of the Troy sewers. The death rate in Albany was reduced by the use of the filters as much as it has been at Lawrence.

At Philadelphia the construction of covered sand filters was started in 1900, but the work went forward slowly and it was November, 1911, before the whole supply was filtered.

At Washington the construction of covered sand filters

was authorized in 1902, and the plant was put in service in 1905. In this case there has been no marked reduction in the death rate. The reason for this has been made clear by extended investigations. The Potomac River water used for supplying the city, after passing through the settling basins, which held a week's supply, and in which much bacterial purification took place, was not the principal source of typhoid fever in Washington nor an important cause of other water-borne diseases.

The amount of sewage entering the Potomac above the intake is only a small fraction of the amounts entering the Merrimack above Lawrence and the Hudson above Albany.

Providence installed a sand filtration plant, which was put in service in 1905. Denver is mainly supplied by water from sand filters, in service since 1902. Pittsburgh has built an extensive plant with covered filters which has been in service since 1909.

Among the improvements in sand filters are the developments of methods of washing and preparing filter sand, and of cheaply removing and cleaning it after it has become dirty from use, and of replacing it.

The first of these improvements has made it possible to secure at moderate expense a filter sand of the best quality in places where otherwise the use of filters of this type would have been difficult. The second has resulted in a great reduction in the cost of filtration. For example, the cost of labor for removing, washing, and replacing sand at Washington is about $0.60 per million gallons, as compared with about $6.00 at Lawrence in the early days before labor-saving devices were installed.

PARTIAL LIST OF PLACES IN THE UNITED STATES WHERE FILTERS ARE AT PRESENT IN USE

MECHANICAL FILTERS

Place.	Population, 1910.	Capacity of filters in millions of gallons per day.
Cincinnati	363,591	112
New Orleans	339,075	44
Minneapolis	301,408	20
East Jersey Water Co.	300,000	32
Hackensack Water Co.	250,000	24
Louisville	223,928	37
Columbus	181,548	30
Toledo	168,497	20
Atlanta	154,839	21
Scranton	129,867	6
Grand Rapids	112,571	20
Kansas City, Kan.	82,331	6
Youngstown	79,066	11
St. Joseph	77,403	11
Fort Worth	73,312	5
Evansville	69,647	12
Norfolk	67,452	8
Oklahoma City, Okla.	64,205	4
Harrisburg	64,186	12
Charleston	58,833	5
East St. Louis	58,547	11
Terre Haute	58,157	9
Binghamton	48,443	8
Little Rock	45,941	5
York	44,750	4
Chattanooga	44,604	9
Davenport	43,028	7
McKeesport	42,694	10
Augusta, Ga.	41,040	6
Macon	40,665	...

MECHANICAL FILTERS—*Continued.*

Place.	Population, 1910.	Capacity of filters in million of gallons per day.
San Diego	39,578	5
Chester	38,537	4
Montgomery	38,136	1
Elmira	37,176	7
Quincy	36,587	4
Knoxville	36,346	4
Newcastle	36,280	4
Springfield, Mo.	35,201	6
Lexington, Ky	35,099	3
Oshkosh, Wis	33,062	2
Cedar Rapids	32,811	2
Decatur	31,140	...
Niagara Falls	30,445	16
Lorain	28,883	9
Danville, Ill	27,871	6
Newport, R. I	27,149	6
Watertown, N. Y	26,730	6
Waterloo, Ia	26,693	...
Columbia, S. C.	26,319	8
Elgin	25,976	2
Kingston	25,908	...
Wilmington, N. C	25,748	2
Newark, Ohio	25,404	2

And about 250 smaller plants.

SAND FILTERS.

Place.	Population, 1910.	Capacity of filters, million gallons per day.
Philadelphia	1,549,008	420
Pittsburgh	533,905	100
Toronto	376,538	60
Washington	331,069	87
Indianapolis	233,650	24
Providence	224,326	24
Denver	213,381	30
New Haven	133,605	15
Albany	100,253	17
Reading	96,071	22
Springfield	88,926	15
Wilmington	87,411	15
Lawrence	85,892	6
Yonkers	79,803	10
Superior	40,384	5
Mount Vernon	30,919	3
Poughkeepsie	27,936	5

And about 25 smaller places.

CHAPTER IX.

ON THE NATURE OF THE METHODS OF PURIFYING WATER.

THE general natures of these methods are elsewhere noted in connection with the descriptions of different kinds of water that require treatment. A brief statement of the natures of the various processes at this point may be helpful, even though some of the matter is repeated.

The processes of water purification may be briefly classified as follows:

I. *Mechanical Separation:*
  By gravity — Sedimentation.
  By screening — Screens, scrubbers, filters.
  By adhesion — Scrubbers, filters.

II. *Coagulation:*
  By chemical treatment resulting in drawing matters together into groups, thereby making them more susceptible to removal by mechanical separation, but without any significant chemical change in the water.

III. *Chemical Purification:*
  Softening — by the use of lime, etc.
  Iron removal.
  Neutralization of objectionable acids, etc.

IV. *Disinfecting Processes:*
  Hypochlorite of lime.
  Chlorine gas.
  Ozone.
  Sulphate of copper.
  Violet ray treatment.

The object of these processes is to poison and kill objectionable organisms, without at the same time adding substances objectionable or poisonous to the users of the water.

V. *Biological processes:*

Oxidation of organic matter by its use as food for organisms which thereby effect its destruction.

Death of objectionable organisms, resulting from the production of unfavorable conditions, such as absence of food (removed by the purification processes) killing by antagonistic organisms, etc.

VI. *Aeration:*

Evaporation of gases held in solution and which are the cause of objectionable tastes and odors.

Evaporation of carbonic acid, a food supply for some kinds of growths.

Supplying oxygen necessary for certain chemical purifications, and especially necessary to support growths of water-purifying organisms.

VII. *Boiling:*

The best household method of protection from disease-carrying waters.

These are the most important ways in which water is cleaned and purified, but the classification is necessarily imperfect and inadequate because each of the actions mentioned is related to and grades into some of the others, and in many cases it cannot be determined how much of the purification effected by a given process is brought about in one way and how much in another. For instance, in filtration it is known that the straining out of suspended matters, the sedimentation taking place in the pores of the filtering material, and the adhesion of the suspended particles to fixed particles of filter-

ing material, are all important in bringing about purification, and in addition, there is also taking place at the same time and in the same place a whole series of biological changes, so complicated that at the present time only a general outline of their nature is understood.

In a similar way, coagulation is usually effected by a chemical process, and some chemical change in the water is produced by the treatment, although this is not its direct and principal object.

Sometimes two processes are combined, as where river water is softened by chemical treatment in such a way as to produce a coagulating effect upon the suspended matters.

Many of the disinfectants are powerful oxidizing agents. Hypochlorate of lime, liquid chlorine, and ozone are among the most powerful oxidizing agents known. In addition to killing the objectionable organisms, there is sure to be direct chemical action resulting from these substances which tends to the purification of the water, and at the same time to the destruction and elimination of the applied substances from the water. These secondary actions are often of great importance. If ozone is applied to a dirty water in quantity sufficient to kill the objectionable organisms in clean water, it may happen that the impurities in the water will absorb and use up the ozone so rapidly that it will not have a chance to act upon the organisms, and the desired effect will not be produced. For this and other reasons it is not advisable to apply such oxidizing agents to dirty raw water. So far as they can be used with advantage they must be applied to waters that have already been filtered and

oxidized and largely purified by other and cheaper methods.

Straining. This is used particularly to remove fish and floating leaves, sticks, etc. Coarse screening is best effected by passing between steel bars arranged to be easily raked off. Fine screening is most frequently done through screens covered with wire cloth, arranged in pairs so that one screen is raised for cleaning while its mate is below in service. Such screens are often made large and heavy and are raised by hydraulic or electric power.

Revolving screens are also used, and they are better. They are of two general types. In one the screen runs as a link-belt over pulleys above and below; in the other the screen is in the form of a cylinder partly immersed in the water and passing between guides which insure the passage of all the water through it. In either case the motion of the screens is continuous, and cleaning is done in the part of the screen above the water by jets of water playing upon it.

Screens are largely used in paper mills, wire cloth having as many as sixty meshes per lineal inch being often employed.

Many elaborate screening arrangements have been installed for unfiltered reservoir waters, in the hope that algæ and other organisms would be removed by them. Some organisms are removed, but the most troublesome ones and their effects are not removed or even sensibly reduced by screening.

Screening as a preliminary to filtration is often used, and within certain limits is advantageous; but close

screening is unnecessary, and in many plants there is no screening before filtration and no need of it.

Sedimentation. This consists in taking water through tanks or basins in which the velocity of flow is reduced and the heavier suspended matters are taken to the bottom by gravity. The accumulated sediment is removed from time to time. Sedimentation is widely used as a preliminary process and is the cheapest way of removing those relatively large particles which will settle out in a moderately short length of time.

It pays to remove such particles in this way when they are numerous, even though other and more thorough processes are to follow, as the subsequent processes are more easily and effectively carried out in the absence of heavy suspended matters.

Scrubbers. These are rapid, coarse-grained filters, or their equivalent. They have been used to a considerable extent in recent works. To some extent they are used in place of sedimentation, doing about the same work, but doing it quicker and in less space, though usually at greater cost; and to some extent they carry the process further, removing smaller and lighter particles than could be readily removed by settling alone.

Scrubbers act in part as strainers, but the principal action is apparently the sedimentation which takes place in the pores of the scrubbing material, where conditions of sedimentation are extremely favorable.

It is very easy to build a scrubber to do good work. It is more difficult to build one to do this and also be capable of being cleaned in a cheap and efficient manner. From the standpoint of design and construction,

the cleaning devices are the most important parts of a scrubber.

Mechanical Filters. This is a most important type of apparatus. It is an arrangement for passing water through a sand layer at a relatively high rate, with devices for cleaning the sand when it becomes dirty, by reversing the current, and by other means, and of all necessary auxiliary apparatus for regulating and controlling the process.

The term mechanical filter came from the mechanical nature of the appliances used for cleaning the sand.

There are many types of mechanical filters and there has been a great development in the devices used. The substitution of concrete, bronze, and other durable materials for the wood and the rapidly corroded iron and brass of the earlier designs, is conspicuous, but in addition, developments in the direction of simpler and more adequate and effective devices have been most important.

From the standpoint of design and construction the cleaning devices offer far greater difficulties than the filtering devices.

In mechanical filters the straining action is probably more important than the sedimentation taking place in the pores of the filtering material.

In a few cases mechanical filters have been used as a first or preliminary process, but usually they are employed as a final process of purification. To make them effective in this way the water reaching them must be thoroughly prepared by coagulation or otherwise. That is to say, all extremely small particles must have been

Interior of Filter House. Little Falls Filters of the East Jersey Water Company, showing operating table for mechanical filters.

Courtesy of Mr. G. W. Fuller.

Bottom of a mechanical filter at Watertown, N. Y., with the sand removed to show the water and air piping and strainers.

drawn together into aggregates of sufficient size to be capable of being removed by filtration at a high rate, and the total amount of such particles must have been reduced by subsequent sedimentation to such a quantity that the filtering material will not be too rapidly clogged by them. Without such thorough preliminary treatment mechanical filters are not capable of removing the bacteria, or the finely divided sediment or turbidity, and many other matters requiring to be removed.

Sand Filters. Sand filters are used at a lower rate than mechanical filters, and cleaning is done by removing by scraping of a surface layer of dirty sand instead of by washing the whole sand layer by a reverse current. The cost of cleaning devices being saved, and construction simplified in other ways, as compared with mechanical filters, a far greater filtering area can be provided for the same cost; and filtration being at a lower rate, the straining action is more thorough, and there are opportunities for biological purification. Sand filtration alone, without preliminary treatment, is able to remove nearly all of the objectionable bacteria, as well as other organisms, from many waters, at the same time purifying them in other ways. The straining is not close enough, however, to remove the clay particles that render many waters, especially some river waters, turbid, and such waters require preliminary treatment.

Sand filters are used in connection with various preliminary treatments, but, generally speaking, they are adapted to treating only such waters as are capable of being purified in that way without any preliminary treatments, or with only rough and inexpensive treatments

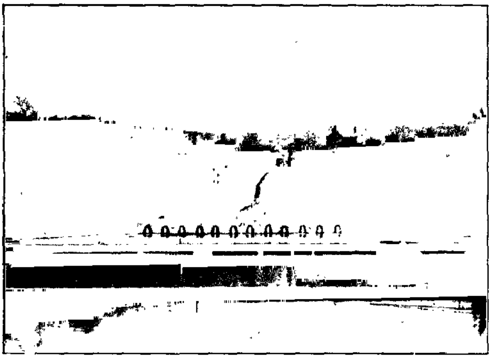
If the water ordinarily requires coagulation, then, as a rule, it will be better to make the coagulation thorough and use mechanical filters for the final treatment.

Coagulating Devices. Coagulating devices consist of apparatus for dissolving the chemical or chemicals used for coagulating the water, and for mixing the solutions, and bringing them to the required strengths, and for applying them to the water, and mixing them with it, and all auxiliary appliances.

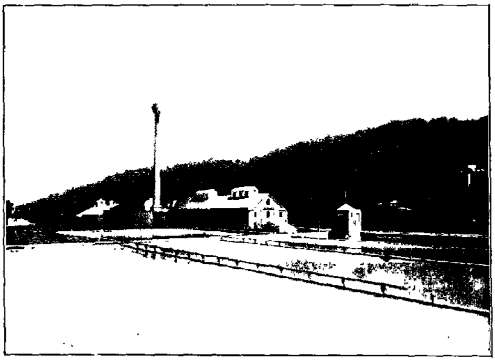
There is great variety in coagulating devices, and much ingenuity has been displayed in meeting special conditions. There is no great or insuperable difficulty in securing the regular and proper addition of coagulant to a water, and in many cases this has been done in a perfectly satisfactory way. On the other hand, the coagulating devices have probably failed to act more frequently than any other part of the plants of which they form parts, and for this reason the greatest care must be given to their design and operation.

In the last few years a new type of coagulating apparatus has appeared, known as the dry-feed apparatus. With it the chemical in pulverized form is fed mechanically at a fixed rate to a dissolving box. An excess of water flows through this and dissolves the chemical as it is delivered and afterwards mixes with the water to be treated. The rate of application is controlled by changing the gearing or other mechanical control.

The dry-feed process originated in St. Louis, but in this case the chemicals were weighed out and put by hand into the dissolving box at determined intervals. The same



Coagulating and sedimentation basin with aeration of entering water and with thorough baffling to assist sedimentation. South Pittsburgh filters.



Coagulating and sedimentation basin with baffles and pumping station and filter house at St. Joseph, Missouri.

Courtesy of American Water Works and Guarantee Company.

general method has been followed at Cincinnati and more recently at Washington.

The more recently installed machines have been made entirely automatic in their action, and after filling the attached hoppers, which may hold hours' or even days' supply, the application is continued without labor and with only occasional attention at the rate for which they are set.

Coagulating Basins. Coagulating basins are required to hold the water for a time after it has received the coagulant or coagulants, to allow the chemical reactions resulting from the treatment to take place. They also serve to remove by sedimentation the greater part of the precipitate that results from these reactions. This feature is of the utmost importance, as otherwise the precipitate would choke the filters, and cleaning would be required too frequently. The bulk of the precipitates should always be removed before the water goes to the filter, and to this end baffles and other devices tending to complete sedimentation are desirable, and the bottoms of the basins are made with slopes and gutters to facilitate the easy and frequent removal of the mud which is deposited upon them.

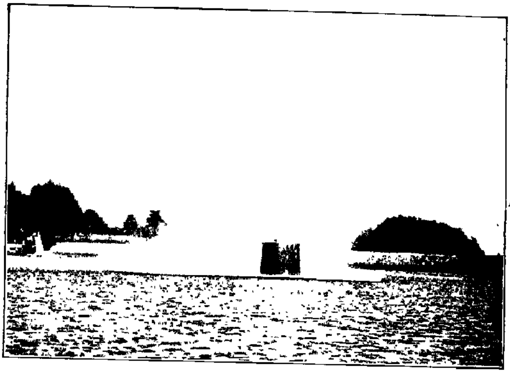
Aerating Devices. Aerating devices are used to bring the water in contact with air, either for the purpose of introducing oxygen or of removing carbonic acid or gases which produce tastes and odors. The natural flow of water in the bed of a mountain stream having a rapid fall aerates it in a most effective way, and many works are so arranged that this kind of aeration is utilized. Flow in sluggish streams or canals has comparatively little value for aeration.

When aeration must be done with artificial appliances, playing the water in jets forming fountains is one of the most effective ways, but to be thoroughly efficient considerable head is used up, and this is a serious obstacle, when the water is pumped, because of the cost. In other cases the water is allowed to fall through the perforated bottoms of trays, and similar devices. Under some conditions flowing over or through coke or other coarse-grained ballast seems to aid, but it is essential that the air in the voids of such material should be frequently changed by some certain means, as otherwise the materials instead of being helpful will greatly reduce the amount of aeration obtained.

When aeration is used to introduce oxygen, a substantial result may be obtained by well designed appliances with a drop of not more than two or three feet in water level. Much more extended aeration is required to remove objectionable gases from a water, and a greater head may be advantageously used where they are troublesome.

Intermittent filters can be operated so as to thoroughly aerate the water passing them, so long as the water quantity and the amount of organic matter in it are not too large, having reference to the grain-size, depth, and condition of the filter sand; and for this reason this form of filtration has advantages when much aeration is required.

The above outlines of the most important processes of water purification, and of the appliances used to carry them out, is intended only to give a general idea of what is aimed at, and of the objects of the various parts of the



Aeration of Hemlock Lake water at Rochester, N. Y., resulting in a reduction of tastes and odors.
Courtesy of Mr Emil Kuichling.

An Efficient Aerator. Temporary Bronx Supply, New York City.

works, and no detailed descriptions are necessary for this purpose. In the same way only those methods and appliances of some practical importance are included. A great number of other processes have been proposed, and a few of them may be in time developed so as to be of practical value. But a discussion of such processes, not yet brought to successful application, would not aid in a clear understanding of first principles.

It is worth noting that most of the advance in water purification comes from the development of old processes. It is only at long intervals that a new method or principle of treatment is discovered that is important enough to find a permanent place in the art.

CHAPTER X.

DISINFECTION.

THE possibility of protecting the users of water from infection carried by it by means of chemical treatment has been recognized almost since the discovery of the part played by water in transmitting certain disease germs.

At about the time of the cholera epidemic in Hamburg the German technical papers contained discussions of the availability of a number of metallic salts for use in this way; and in the years that followed some of these, especially copper sulphate and permanganate of potash, were occasionally used, most often in small or special supplies. For instance, permanganate of potash was used in treating waters supplied to armies in certain campaigns, and the benefits from its use were undoubtedly great.

Treating water in this way may be compared to spraying fruit trees. Its object is to prevent the propagation of organisms that would be destructive, and to do this by the use of substances that are not injurious to those that are to be protected.

Little progress was made in applying processes of disinfection to public-water supplies until the year 1908. Chemical treatment was involved in them, and popular prejudice against its use was strong. In that year, to

meet an urgent need for greater bacterial efficiency, one of the best and least injurious disinfectants, hypochlorite of lime, was added to water drawn from the Boonton reservoir to supply Jersey City. It was found that in this way a great reduction in bacteria was obtained, and this result was reached with a smaller amount of the disinfectant than could have been anticipated from any previous experience on a small scale. The fact of the great efficiency of very small doses of this substance has been amply demonstrated by subsequent experience, although the reason for its efficiency has never been fully explained.

Prior to the date mentioned efforts had been made for many years to use ozone as a disinfectant. Ozone is produced by the discharge of high-tension electricity through air under certain conditions. The air is afterwards pumped through the water to be treated, or otherwise the water is showered downward through towers in which the air that has been ozonized is circulated.

In the early ozonizers a large amount of current was required to produce a small amount of ozone and the process was an expensive one. It is necessary for success to bring the ozonized air into intimate contact with all of the water to be treated and the difficulty of doing this proved to be great and added to the expense of applying it.

The efficiency of the ozone treatment properly and adequately carried out had been abundantly demonstrated, although the difficulties and expense had prevented its practical application on a large scale.

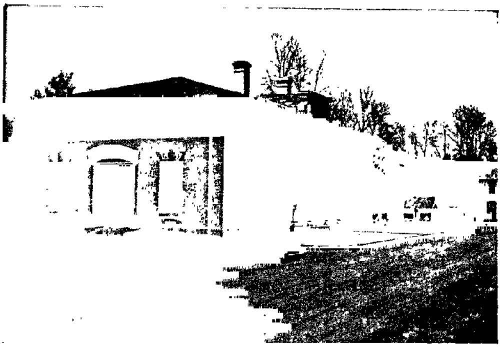
It was soon discovered that the hypochlorite of lime was

practically equivalent in disinfecting power to ozone, on the basis of molecule for molecule of effective oxidizing material. The hypochlorite of lime produced practically equivalent results from the standpoint of disinfection, at a cost so low that it could be used in any public water-works plant where it was required or advantageous. The cost of the material was frequently not more than fifteen to twenty-five cents per million gallons; and even when the greater cost of applying it was taken into account, the whole cost of the treatment, including capital charges, might not be more than a tenth of the cost of filtration.

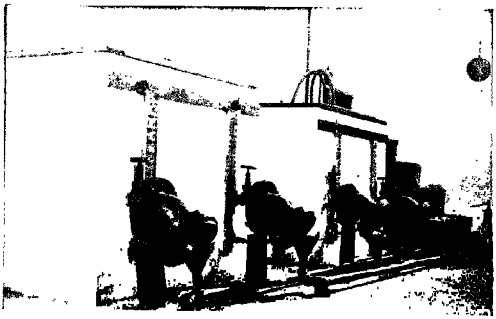
When the advantages to be obtained by this simple and inexpensive treatment became realized, as a result of the publicity given by the Jersey City experience, the use of the process extended with unprecedented rapidity, until at the present time the greater part of the water supplied in cities in the United States is treated in this way or by some substitute and equivalent method.

Method of Treatment. Hypochlorite of lime, or bleaching powder, is a by-product from the manufacture of soda ash, and is readily obtainable in large quantities. The material is dissolved in water in large tanks, and thoroughly mixed, making a solution of standard strength. This solution is applied through control devices to the water to be treated.

It is necessary, in order to secure the full efficiency, that the solution should be thoroughly and quickly mixed with the water to be treated, and it is desirable that the water after receiving the dose should be kept from mixing with the other water that has been previously treated, as would be the case if it were to be



Coagulant House, Washington Filters, where chemicals are mixed and applied to the water before filtration.



Measuring-tanks for Controlling the Application of Hypochlorite of Lime to Filter Effluents, Yonkers, N. Y.

discharged at once after treatment into a large reservoir. It suffices if the treated water flows for some distance in a pipe or aqueduct, or is kept in a small chamber or a compartment in a large one.

This treatment has been carried out as an independent process for many waters that are not otherwise purified. It has also come to be a well-established auxiliary process to filtration. Considerable chemical skill is required to secure the utmost results to be obtained in any case without on the other hand producing certain undesirable conditions which result from an overdose.

All natural waters contain more or less organic matter capable of absorbing chlorine, which is the active principle of the hypochlorite of lime. The absorption of chlorine goes on gradually and is ordinarily complete. That is to say, before the water reaches the consumer, the organic matters in the water take up all the chlorine that is applied. The dose must be adjusted to the water so that enough chlorine will be provided to supply these organic matters with what they require at once and to leave for a certain period a sufficient amount in the water to bring about its disinfection.

The amounts of chlorine that different waters will take up vary greatly, and even in the same supply the amount varies from winter to summer and even from day to day. For this reason highly colored river water may require several times as large a dose as lake or filtered water that is relatively clean and colorless. A dose of ten pounds per million gallons may be sufficient with the latter. If a dose of this size should be applied to the former the whole of the chlorine would be absorbed

by the organic matters so quickly as to have practically no disinfecting value. On the other hand, a dose adapted to a water high in organic matter, if applied to a relatively clean water, would leave an excess of chlorine disagreeable in taste and odor and highly objectionable to consumers.

In view of the difficulty of adjusting the dose of chlorine accurately to all the varying conditions of the water treated, the plan has been suggested (and used to a limited extent) of using a moderate excess of disinfectant, and of applying to the water after the expiration of a certain time a dose of some harmless substance capable of absorbing and removing any chlorine that may be left. Thiosulphate of soda has been most frequently used for this purpose.

Chlorine has a distinct and disagreeable taste and smell, and if too much of it is applied some of it may remain in the water. As a practical matter this rarely happens, because there is almost always organic matter enough to take up the amount that is used in the time that elapses before the water reaches the consumers. What does happen is that the chlorine acts on some of the organic matters present in the water, changing their nature so that they do produce disagreeable tastes and smells. There is more danger of producing this result if the dose is large than if it is small.

There is a great difference in waters in this respect. Some carry organic matters that seem capable on the slightest provocation of being changed into bad-smelling chlorine-substitution products, while others are free from such materials and will easily carry a larger dose with little risk.

Unfiltered surface waters carry matters in suspension, and the objectionable bacteria may be in the interior of bunches or clots of suspended matter, where they will not be reached by the disinfecting action of the chlorine during the period in which the chlorine is in the water. The organisms so protected may remain and afterwards be scattered with danger of carrying any infection that may have been present. For this reason the treatment as applied to raw waters is much less certain in its action than it is when applied to clear filtered waters, even though, as is usually the case, the applied dose is much larger.

Disinfection in Connection with Filtration. Disinfection has come to be regarded as a most important auxiliary process. It has been sometimes used on the raw water going to the filters or on the coagulated water after the flow has settled and before the water goes to the filters, or otherwise on the filtered water.

Greater efficiency in the removal of objectionable bacteria is obtained when the dose is applied to the water after filtration; but there is more risk in producing tastes and odors when it is used in this way. When it is applied in advance a larger dose is necessary, and the efficiency obtained is smaller; but on the other hand, the action of the filter in removing and reducing tastes and odors produced by the action of the chlorine on the organic matters of the water is made available; and where the range between the minimum dose that is sufficient for disinfection and the maximum dose that can be used without producing tastes and odors is narrow, the advantages of the earlier application are important, even though the utmost efficiency cannot be obtained.

In some cases disappointing results have followed the treatment of the water prior to filtration, growing out of the temporary use of an over-dose, which has had the effect of killing organisms in the filter that were performing useful service in the process of purification, and the resulting demoralization of the filters.

The use of processes of disinfection has made a profound difference in the way in which other processes of purification are regarded. It has made it possible to secure as an ordinary working process to be carried out 365 days in the year a higher degree of bacterial removal than was previously possible; and on the other hand, it provides a substantial although not absolute safeguard against occasional reductions in the efficiency of processes that grow out of unusual conditions or lack of attention on the part of the attendants.

Of course all methods of disinfection are at least as susceptible as any other processes to failures growing out of lack of attention by those having them in charge.

Looking at the matter broadly, the use of disinfection has increased very greatly the safety of the water supplies where it has been used.

The most serious practical objection to the use of hypochlorite of lime is from the tastes and odors frequently produced by it, and which with some waters seem to be unavoidable when adequate doses are used. The gain in hygienic safety resulting from disinfection has been so great that there is no thought of abandoning it, but these difficulties with tastes and odors have been such as to lead to renewed study of other methods of disinfection in the hope of finding one less subject to this defect.

Liquid Chlorine. Liquid chlorine has been proposed and is being used on a large scale as a substitute for hypochlorite of lime. The active agent is the same as that in hypochlorite of lime; and it may be assumed that corresponding quantities, molecule for molecule of active material, will be required.

This material is supplied in cylinders under heavy pressure. At present prices it is more expensive than an equivalent amount of hypochlorite of lime, but its application is in some respects more convenient. It is claimed that there is less likelihood of producing tastes and odors than with chlorine in the form of hypochlorite of lime; but experience up to the present time can hardly be considered as sufficient to fully substantiate this view.

Ozone. The ozone treatment previously mentioned is entirely free from this objection. Waters can be treated with any desired amount, and if there is any change, improvement in tastes and odors, and not deterioration, is to be anticipated.

In the past ozone treatment has been too expensive for general use. Much ingenuity has been expended in devising ozonizers of higher efficiency and arrangements for bringing the ozonized air into intimate contact with the water to be treated by simpler and less expensive methods.

Improvement has been made, and further improvements seem possible. Under these conditions it may be that ozone will sometime secure much wider application.

Ultra-violet Rays. The ultra-violet rays have a certain germicidal power, and bacteria may be killed by exposing

water in these layers to the action of lamps producing these rays. This process is attractive as affording a means of disinfection without adding any chemical substance to the water and without any apparent possibility of producing disagreeable tastes and odors.

. **Clear Water Necessary.** All the processes of disinfection to be efficient require that the water to be treated should be free from suspended matter. In other words, it must be filtered water. Reduction in numbers of bacteria may be obtained by applying these processes to raw waters, especially to those containing but little suspended matter, and such treatments may often be advantageous; but a clear water is essential for obtaining the full effects of the various processes, and they are all of them to be regarded as auxiliary processes to be applied for the best results to filtered waters, and not as processes to be solely relied upon.

CHAPTER XI.

ON THE APPLICATION OF THE METHODS OF WATER PURIFICATION, ARRANGED ACCORDING TO THE MATTERS TO BE REMOVED BY THE TREATMENT.

Tastes and Odors. Tastes and odors are to be most frequently found in waters from impounding reservoirs and small lakes, and in our climate such waters are sure to have tastes and odors at times. They have occurred even in those reservoirs where the greatest efforts have been made to prevent them by cutting out shallow flowage and by stripping the reservoir bottoms of soil.

Aeration to Remove Tastes and Odors. The simplest, cheapest, and most generally applicable method of removing tastes and odors is by aeration; that is to say, by bringing the water in contact with air by playing the water into it by fountains or otherwise. The natural flow of water in the bed of a mountain stream over stones and ledges aerates it very well. The exposure of water to the air in reservoirs and in gently flowing rivers or channels certainly tends to aerate it, but far less effect in removing tastes and odors is usually observed from such exposure.

To throw water up in a fountain, which means a contact with the air not exceeding usually two or three, or at the most, four seconds, would seem a very slight treatment for water which has been exposed to the wind

action in a reservoir for weeks or months, but it will often do what the long exposure has not accomplished.

Among the cases where a striking improvement in tastes and odors has followed aeration may be mentioned the following:

Ludlow Reservoir water, played through fountains to Van Horn Reservoir at Springfield, Mass., in the summer of 1905. (This was the first year the fountains were used; the supply was filtered in 1906.)

Grassy Sprain Reservoir water, pumped over an aerating device into the Fort Hill Reservoir at Yonkers.

Water from several impounding reservoirs, let down through natural channels to the old Croton Reservoir supplying New York City.

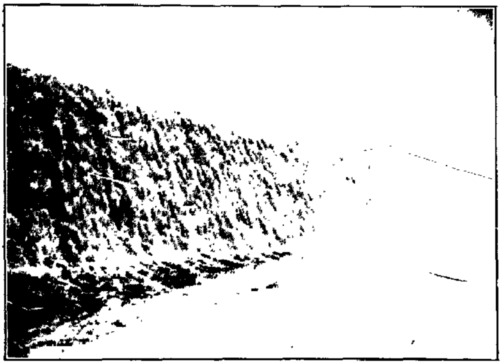
Water let down in the same way from the main upper reservoirs to the small intake reservoir at Newark.

Such aeration always reduces, and sometimes removes, tastes and odors from the waters of the reservoirs and small lakes, whether resulting from putrefaction in summer in the stagnant bottom water or from growths of organisms in the surface water.

Mechanical Filtration to Remove Tastes and Odors. Mechanical filtration was used at Wilkesbarre, Pa., for treating a reservoir water. It did not sufficiently remove tastes and odors, and for this reason the plant was abandoned.

At Charleston, S. C., Goose Creek water, which is subject to very bad tastes and odors, is successfully purified by a process of which mechanical filtration is one step.

Aeration of Missouri River Water in passing from one settling basin to another at Omaha, Neb.



Aeration of water in falling over a stone dam.

The whole process consists of the following:

(1) Use of copper sulphate in the reservoir to hold down growths of organisms.

(2) Aeration of the water.

(3) Coagulation, followed by passage through a basin holding two days' supply.

(4) Aeration of the water on leaving the basin.

(5) Mechanical filtration.

(6) Aeration on leaving the filters.

In the above process the three aerations were not used at first, and without them the tastes and odors were not removed. The addition of the aeration at the places as stated served to make the process reasonably efficient.

In general it may be stated that mechanical filtration is not efficient in removing tastes and odors. Probably in most cases when improvements have followed it, they have resulted more from the incidental aerations than from the filtration.

Sand Filtration to Remove Tastes and Odors. Sand filtration has considerable power of reducing, and in some cases of removing, tastes and odors, but it is not usually to be wholly relied upon when the raw water is very bad.

In England it is used for treating water from impounding reservoirs, and seems to be usually efficient in removing such tastes and odors as there are; but these tastes and odors clearly are far less serious than those in many or most American reservoir waters.

At Reading, Pa., with impounding reservoir waters, subject to moderate but not extreme tastes and odors,

filtration at a rate of from 3,000,000 to 5,000,000 gallons per acre daily is sufficient.

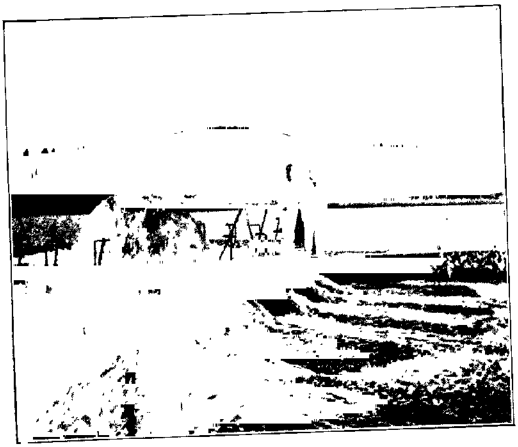
At Springfield, Mass., experiments indicated that such filtration, even when accompanied by aeration, would not suffice to deodorize the water from Ludlow Reservoir, which is exceptionally bad. In this case putting the water through two filters in succession, with aeration before, between, and after, did serve to fully remove the odors.

Intermittent Filtration to Remove Tastes and Odors. Intermittent filtration is a term applied to filters of special construction and operation. The filters are usually drained at the bottom and the outlets are always open to let any water that gets through the filter sand flow away without obstruction. The water to be filtered is applied rapidly to the surface at intervals, with periods of rest between, during which the surface of the filtering material is exposed to the air, and the sand becomes drained. The sand is preferably rather coarser than would be used in ordinary filtration.

Intermittent filtration has been particularly successful in purifying sewage. It is also used for treating manufacturing wastes containing much organic matter. It is successful for these purposes because it brings the organic matter in the liquid in contact with more air, and in more intimate contact with air, and for a longer time, in the pores of the sand than can be secured in any other way. This contact is essential for the oxidation of the organic matter.

The reason why ordinary or continuous sand filtration failed to remove odors in the Springfield tests seemed

Intermittent filters at Springfield, Mass., showing one filter out of use and being cleaned.



Intermittent filters at Springfield, Mass., showing aeration of water at entrance and the distribution of the water to the four filters.

clearly to be that water carried more organic matter than could be disposed of by all the oxygen present, including that furnished by the aeration.

It seemed reasonable to suppose that if more air could be brought in contact with this water the process might be made successful, and the method of intermittent filtration successfully used for this purpose in sewage purification appeared to be the best way of accomplishing this end.

The condition of the water at Springfield being extremely unsatisfactory, this process seemed worthy of a trial. The local conditions proved exceptionally favorable for the construction of this kind of filters. A bank of sand close to the reservoir was found which was of such a quality that it could be used just as it came from the bank for filter sand.

This was leveled off to form a filtering area of about four acres. This was underdrained. No water-tight bottom was provided. Expense was thus saved, though some water was lost, seeping back to the reservoir. A pumping station lifted the water to an aerator, from which it flowed through gates to the four divisions of the filters. The pump was operated about 16 hours daily, the filters being left to drain for the other eight. The plant was built for temporary use only and is no longer used for the Springfield supply, as the city is now furnished with water from a new and larger source. It cost $50,000 to build, and yielded about 12,000,000 gallons a day of water substantially free from tastes and odors, and otherwise improved in quality. The cost of operation, that is to say,

of pumping the water, of caring for the filters and renewing the surface sand, and of maintaining a small laboratory, which was necessary for the operation, with supervision, was five or six dollars per million gallons.

This plant was not capable of operation in winter, and it was not expected to have a high bacterial efficiency, and it would not therefore do for use where the water was subject to pollution.

Intermittent filtration probably has no advantage over ordinary sand filtration with thorough aeration in removing tastes and odors, in those cases where the amount of organic matters associated with them are not excessive; that is to say, where they do not exceed the amounts which the air present in such filtration is able to dispose of.

But where the water is very bad indeed, intermittent filtration with aeration is perhaps the most powerful method at our disposal for removing tastes and odors. The only alternative is the use of successive filtrations with aeration between.

Color. The word color refers to soluble yellow coloring matter extracted from dead leaves, peat, and other vegetable matters, and it is principally found in swamp waters. As previously stated, it is found in many impounding reservoir waters and in river waters in certain parts of the country.

Color is not ordinarily removed to any considerable extent by simple filtration through either sand or mechanical filters.

Color is slowly bleached and destroyed by sunshine. In large impounding reservoirs this is often a matter of

importance, but the action is too slow to be considered in artificial purification.

Ozone destroys color. If it were not for the large cost of producing the ozone, this would be a most desirable method of removing it.

Color is rendered insoluble by certain coagulants and therefore capable of removal by filtration. Sulphate of alumina is most commonly and successfully used for this purpose, and this is at present the usual and most feasible way of removing it.

There are a great many filter plants treating water that is more or less colored, with sulphate of alumina, and successfully removing most of the color. Among these the following may be mentioned.

Norfolk, Va., where a very highly colored water from small lakes and streams is used. This water is coagulated, stored in a natural basin to allow the action to become completed, and is then passed through mechanical filters of the so-called Jewell type.

Charleston, S. C., where the water is treated as previously described in connection with tastes and odors. The sulphate of alumina used in the treatment serves to decolorize the water. As there is not enough alkalinity naturally present in Goose Creek water to react with the coagulant and to combine with the acid constituent of it, lime is added to the water in sufficient amount to do this. The lime so added does not act as does lime added to a naturally hard water. There is no precipitation of lime. The whole amount added remains in solution and makes the water so much harder.

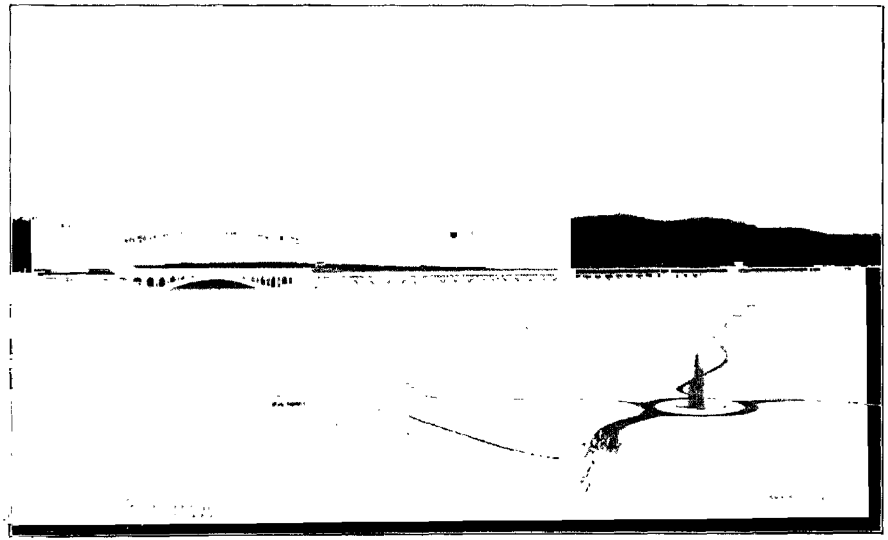
Watertown, N. Y., where Black River water is coagulated with sulphate of alumina, and is then filtered through mechanical filters. Soda ash is used to make up deficiency in alkalinity on the few days in the year that it is necessary.

All the above mentioned waters are very highly colored and are satisfactorily decolorized by the treatment. If smaller plants and less deeply colored waters were included, the list could be indefinitely extended.

The use of iron sulphate with lime in place of sulphate of alumina has been tried, especially at Quincy and Moline, Ill.; but for color removal this treatment appears to be clearly less satisfactory than the usual sulphate of alumina treatment.

Fermentation of Coloring Matter in the Stagnant Bottom Water of Impounding Reservoirs. When highly colored water is stored in an impounding reservoir, and the bottom water goes through the putrefaction process, it does not directly reduce the color of the water, but it does change the chemical nature of the coloring material in such a way that it may afterwards be removed to a considerable extent by filtration without chemical treatment.

The river waters filtered without coagulation at Lawrence, Albany, and many other places, are more or less colored. And some of this color is always removed by the filtration. The amount of removal ranges from a fifth to a third. As a general average a reduction of 25 per cent is obtained. And in the filtration of reservoir waters that have not been through the putrefactive



The new Croton Dam holding back water for the supply of New York City.

process about the same proportion of removal is obtained.

On the other hand, highly colored waters from deep reservoirs are often easily and almost completely decolorized. In visiting the Rivington works of the city of Liverpool in 1896, the writer was deeply impressed with the almost complete removal of the high color of the reservoir water by simple filtration through ordinary sand filters. In the experiments at Springfield on the Ludlow Reservoir water to remove tastes and odors a very high degree of color removal was obtained, and the filters since built to deodorize the water also serve to decolorize it to an extent that would be altogether impossible with river water or with reservoir water which had not been subject to putrefaction.

At Charleston, S.C., with Goose Creek water, coagulant is used, but the amount required to decolorize the water is much less than would be necessary for the treatment of a river water of equal color. In this case it is to be noted that Goose Creek Reservoir is far too shallow to have a permanent stagnant layer; but nevertheless very strong putrefaction changes do take place in the water near the bottom. This water which has putrefied is mixed by the wind with top water from time to time, and the whole body of water has to a large extent the character of bottom water from a deep reservoir, and at the same time it contains the organisms usual in top water.

The putrefaction may bring about some changes in the coloring matter itself, which renders it more easy of

removal, but the principal cause of the change in character seems to be associated with the condition of the iron that is always present in these waters. During the putrefaction the oxygen dissolved in the water is exhausted, and the iron is reduced from the ferric to the ferrous state. Iron is freely taken into solution under these conditions from the materials of the bottom of the reservoir, and these are pretty sure to contain a sufficient supply of it. The bottom stagnant water of reservoirs nearly always contains far more iron than the water entering the reservoir.

Now when this water is aerated the iron is oxidized again to the insoluble ferric state. If there is enough iron present in proportion to the coloring matter, it will precipitate out forthwith. In doing this it acts as a coagulant upon the coloring matter and removes it. If the amount of iron is small in proportion to the coloring matter, then the organic matter will hold the iron in solution even in the ferric state; but the combination is not quite stable and is easily broken up. It is more likely to be broken up and removed in a filter than in a reservoir. There are three possible conditions resulting from the putrefaction followed by aeration, depending upon the relative amount of iron and coloring matter, and how far the putrefaction has gone, namely (1) there may be an immediate flocculent precipitate, such as would be thrown down by sulphate of alumina; or (2) the water may show no physical change, but still be in condition where the matters will be removed by filtration without further preliminary treatment; or (3) the com-

bination of iron and organic matter may be too stable for removal by filtration; but it has nevertheless been so far changed that it can be removed by a smaller amount of coagulant than would otherwise be necessary for the removal of the coloring matter.

The action of iron in reservoirs, its accumulation and separation after aeration, were studied by the late Dr. T. M. Drown, and by Mr. Desmond FitzGerald and others in Boston, especially about 1890-93, and became fully understood at that time; but more than ten years elapsed before practical advantage of these actions was taken in decolorizing water. In England, it is true, it plays, and for many years has played, an important part in cleaning reservoir waters; but this seems to have been rather accidental than intentional, and there seems to be no reason to believe that the process was ever thoroughly understood or that efforts were made to facilitate it.

It is probable that in future much more extended use will be made of this method of decolorization of reservoir waters, especially as the treatment is also substantially that adapted in the removal of odors and tastes from these waters, and the two objects are thus secured by the same treatment.

Turbidity. Practically the turbidity question may be limited to river waters. Lake and reservoir waters are occasionally turbid, but seldom in a way to be seriously troublesome, or to such an extent that they cannot be cleaned by methods of treatment which might be

adapted to purify the waters in other respects. All river waters are more or less turbid at times, but the differences between different river waters are very great indeed.

In a general way the turbidity question is not a difficult one in that part of the United States which was once covered with glaciers. South of this area turbidity is of such importance as practically to control the methods of treatment that must be used. This division obviously is a rough one, with many exceptions both ways, but it does represent the predominating conditions.

The conditions in the northern or glaciated area correspond more nearly with European conditions, and it is in this area only that comparisons with European practice are helpful.

In water purification there are two matters to be ascertained as to turbidity. First, how much turbidity is present in the water; and second, how small are the particles that constitute it.

If the turbidity is sufficiently coarse grained, it can be removed by sand filtration without previous chemical treatment. If it is present in large amounts, it can be cheaply removed in part in settling basins, and in this way the work of the filters can be lightened, and the cost reduced. And that work can be still further lightened by the use of preliminary or roughing filters, which do the work of sedimentation basins, but perhaps more quickly and more thoroughly.

Much of the turbidity of certain northern rivers is of this coarse-grained variety, but it is seldom present in

large amounts, or continuously; and when it is only present once in awhile, investment in roughing filters or even in sedimentation basins may be of doubtful economic value. It is very easy to spend on such works more than can possibly be saved in the cost of the subsequent filter operation.

Altogether the coarse-grained turbidity does not present a very serious problem in water purification.

In that part of the country which was not glaciated, and this includes the lower Susquehanna basin, much of the Ohio basin, and the Missouri basin, and all to the south of them, turbidity is often present in large amounts, and it is usually composed of extremely fine grains, and the water often runs turbid in the streams continuously for weeks and even for months at a time. In fact there are some rivers of which the waters are nearly always turbid.

There is one known way of removing turbidity from these waters, and only one; that is by coagulation or chemical precipitation.

Without such treatment, no amount of filtration, single or double, or multiple, will remove it. With such chemical treatment adequately carried out, the simplest and easiest filtration will suffice to make the most refractory water as clean as distilled water.

There are a number of chemical treatments that are used, according to habit and other circumstances. These are all closely related to each other, and are frequently combined to a greater or less extent so that strict classification is not possible.

The substance first and most generally used for this treatment is sulphate of alumina.

When the amount of lime naturally present in the water is not sufficient to effect a complete reaction with it, lime must be added in connection with its use. Soda ash may be used in place of lime, at somewhat greater expense, but with the advantage that the water is not hardened. Generally, however, there is enough lime present for the reaction in excessively turbid waters, and the use of lime for this purpose is not very common.

Sulphate of iron, or copperas, is also extensively and successfully used in treating turbid waters. A greater degree of alkalinity is required to precipitate this substance, and lime must always be used in connection with it. And by using more lime, some of the lime naturally present in the water can be thrown down together with that added, thereby softening the water as well as removing the turbidity from it.

Under some conditions it would seem that the precipitation of the lime and magnesia of the water by lime alone would at once soften it and suffice to coagulate the turbidity, but it does not seem likely that this reaction can often be fully depended upon. The lime and magnesia precipitates do not have as great a coagulating value as those of iron and alumina.

Lime and iron are cheaper than sulphate of alumina, and there are great advantages in their use in large plants. Their application is much more difficult to control adequately, and it should not be undertaken except with the assistance of a competent resident chemist and good

appliances for adding the lime in any quantity that may be required by the composition of the water.

This method of treatment leaves the water with an unnatural deficiency of carbonic acid. It is necessary that the carbonic acid should be absent to allow the reactions to take place which result in the coagulation. But there is a question as to the desirability of supplying water for use in this condition. Such water always tends to deposit a coating of lime upon everything with which it comes in contact. This is more apt to be the case where the coagulating basins in which the reactions take place are not very large.

It has usually been thought necessary to restore to the water a normal amount of carbonic acid at the end of the process. This is done, for example, at the softening plant at Winnipeg, by burning coke and allowing the water to fall a short distance through a space containing the products of combustion of the coke, of which products of course carbonic acid gas is the important one.

At St. Louis the water is subjected to the iron and lime treatment, followed by subsidence in large basins, in which the bulk of the precipitate settles. The partially purified water is then sent to the city without filtration or recarbonating, or other treatment. While the result is very far from ideal, the improvement over previous conditions is so marked as to be generally satisfactory.

Softening. Softening in connection with the treatment of turbid river waters has just been mentioned. Ground waters are also softened. In fact, up to the present time

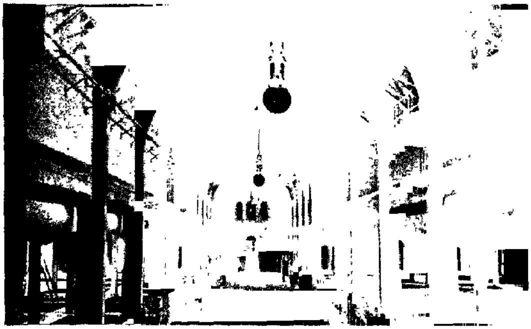
most of the softening that has been done has been of ground water.

The method is that of the old Clark process. The lime of the water is precipitated by other lime that is added to the water for that purpose, and the resulting precipitate of carbonate of lime is settled, strained, or filtered from the water. There are many appliances for carrying out this process. Most of them are specially adapted to moderately small plants, such as those softening water for boiler-feed purposes. Such plants have been extensively installed by the railroads in some parts of the country, and also by manufacturing establishments.

Winnipeg, Canada, has the most important municipal plant in America for softening ground water.. Oberlin, Ohio, softens reservoir water. In addition there are the plants which in connection with other treatments partially soften river waters.

Iron Removal. Iron is troublesome only in ground waters. Its removal is a distinct process, rarely combined with purification for any other purpose. In most cases the iron can be removed with such ease and with such simple appliances that the purification is easier and cheaper than any other water treatment except the removal of odors by aeration.

It is simply necessary to thoroughly aerate the water to remove the excess of carbonic acid, and introduce the oxygen needed to oxidize the iron from the soluble ferrous state in which it exists in the water, to the insoluble ferric state. It can then be removed by filtration. The precipitated iron is very easily removed, and the filtration



Interior of Mechanical Filter Plant, Minneapolis.

Softening plant for reservoir water at Oberlin, Ohio.
Courtesy of Mr. W. B. Gerrish.

may be rather rapid, and the appliances simple and inexpensive.

Occasionally, as at Reading, Mass., and at Superior, Wis., the iron is held more firmly in solution in some unknown way and will not separate so easily. In these cases either one must be contented with a partial removal (which may, however, answer practically very well) or more vigorous chemical treatment must be given.

Removal of the Effects of Sewage Pollution The problem of removing the effects of sewage pollution from a water by artificial purification is, from a sanitary standpoint, the most important of all, and the one that occurs most widely. It is also the one which has been longest and most carefully studied and in regard to which there is the most information.

Sewage pollution is most important in river supplies, as practically all large river waters are more or less subject to it. It is also important in many or most supplies from large lakes. It is far less important for supplies from small lakes and impounding reservoirs, but even in such cases there is often population upon the catchment areas which makes it worth while in selecting a method of purification to get one that is capable of dealing with the effects of sewage pollution.

This can be done without difficulty. The methods of purification adapted to the removal of turbidity and color are also adapted to bacterial or hygienic efficiency, although many precautions must be taken which would be unnecessary if there were no hygienic conditions to be met.

Sand Filtration, for the Removal of the Effects of Sewage Pollution. On the whole, the best results in water purification, as measured by the improvement in the health and the reduction of the death rate among those who use the water, have been obtained with sand filters. This is probably because the method is an old one, has been long and carefully studied, and has been applied on a large scale in well perfected forms for many years, rather than to any natural superiority of the method. There are also cases where inadequate purification has been obtained by this method, resulting from defective construction or from defective operation, where sickness and death have resulted. But such cases have not occurred in plants of the better class which are carefully operated.

Mechanical Filtration, for the Removal of the Effects of Sewage Pollution. Most of the mechanical filters now in use in America have fallen very far short in hygienic efficiency. The greater part of them are of old and inferior types.

Even with these old plants with skilful manipulation it is often possible to get fairly good results; but these older plants have seldom had skilful, and often not even intelligent, manipulation; and it is no wonder that they have so often fallen short of what was expected of them. It is rather to be wondered that with the appliances and men that have been used, so much has been accomplished with them.

All the larger and more recent plants of this type have been equipped with many devices for performing the various operations better than was formerly possible, and

General View of Washington Filters. The filters are covered and the top is grassed over and used as a park.

Interior view of a filter at Washington, showing the hydraulic removal of the surface layer of dirty sand.

also for doing them more certainly; and in these newer and better plants it has been customary to install a laboratory and to employ a superintendent of experience in operating filters and training in hygiene and bacteriology, to ascertain what is being done at all times.

This supervision has led to great improvements in methods, which were only possible through close and continued study under the actual conditions of operation; and it has done more than all else to insure regularly good results.

At present the mechanical filters of the country that have been constructed and operated in this way are doing as good work, measured by bacterial efficiency, as the corresponding sand filter plants; and there is reason to believe that in time the death rate data will show corresponding results from them.

Other Methods of Purification for Hygienic Efficiency. The hygienic efficiency of other methods of purification need be mentioned only in a very brief way.

Intermittent filtration, as used at the Ludlow Reservoir, Springfield, Mass., has considerable power of bacterial purification, but is by no means equal in this respect to filters of standard construction. The same may be said of the processes of iron removal by aeration and rapid filtration, but in this case the bacterial efficiency will be greater as the amount of iron is greater and exerts a greater coagulating effect upon whatever suspended matter, including the bacteria, there may be in the water.

There is no reason to believe that the preliminary filtration or scrubbing of water, to be afterward passed through

sand filters, contributes to any substantial extent to the efficiency of the process as a whole, precisely as there is no reason for believing that it makes any great difference with the passage of finely divided turbidity through the final filters.

Hygienic Standards of Purification. Before the recent great extension in the use of methods of disinfection, there was a well-marked tendency for water purification methods to crystallize about certain standards. These standards were those in the different methods which served to reduce the turbidity and color to inappreciable amounts, and which, in general, removed something like 99 per cent of the bacteria when those organisms resulting from sewage pollution were fairly numerous in the water. Such filtration, in a general way, cost, including all operating expenses and 5 per cent on the required capital, something like $10 per million gallons of water treated. There was no final reason for such standards. They were adopted by consent because they represented a purification that was reasonably satisfactory and that could be reached at a cost that was not burdensome.

Such purification made the waters of some of the most highly polluted rivers used for public water supplies in the United States, as for example, the Merrimack and Hudson, as safe hygienically, and as satisfactory in every way, as supplies drawn from better sources so far as the results can be measured by the best means at our disposal, namely, by bacterial tests and by the records of the health departments of the various cities

where the waters were used. It is true that the most searching bacterial methods disclosed, in such purified waters (as in relatively unpolluted but unfiltered surface waters), some bacteria characteristic of sewage and undoubtedly derived from it.

The use of methods of disinfection has changed these standards radically. By their use it has been found possible to remove most of the remaining bacteria so that the water supplied can be as easily and certainly held within one-tenth of one per cent of those in the raw water, as it formerly could be held within one per cent. In other words, nine-tenths of whatever danger there may have been in the filtered water can now be removed by this supplementary process at a cost so small as to add but little to the whole cost of purification. In fact, the efficiency with disinfection is frequently so great as to make it permissible to omit certain precautions formerly thought necessary in connection with filters, and so to reduce the cost of filtering until the whole cost of the treatment may be less instead of greater than before.

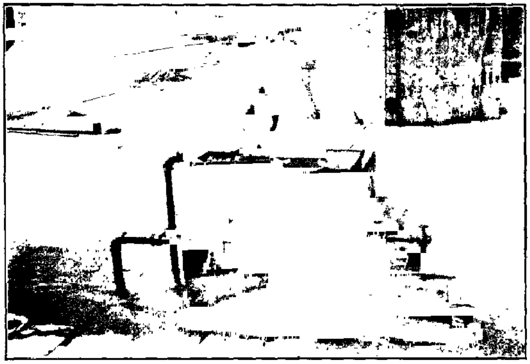
When the conditions of 1913 are compared with those of ten years earlier, there has been an increase in the population of cities discharging sewage to water courses and lakes and an increase in the pollution of the waters. On the other hand, the general introduction of methods of disinfection, improvements in methods of chemical treatment and in other auxiliary processes, and improvements in the art of filtering, have made it possible to produce filtered supplies of greater purity and safety from a hygienic standpoint than could possibly have been

produced at the earlier date. In this interval, looking at the matter broadly, there has been a constant and rapid improvement in the qualities of public water supplies of the country, notwithstanding the increased pollution of the sources.

Even to-day the limit has not been reached. It may be admitted that the time will come when a still higher degree of bacterial efficiency will be required. Present conditions do not seem to demand it, but we must expect that in some time in the future conditions will arise which will make it necessary. When additional purification is required it can be furnished.

There are many ways in which it can be secured. It will be enough to mention the use of lower rates of filtration, of filtering materials with finer grains, of more complete chemical preparation, and of more complete final disinfection by processes that are harmless and that do not injure the water.

It is idle to attempt to decide now how the problem can best be solved when it arises. Even to-day, with the limit of cost raised so that, for example, the cost of the whole process of purification might be raised, let us say, to $20 per million gallons in place of the $10 assumed as the ordinary present cost, works could be designed which would remove the bacteria and other impurities far more completely than any works now in service are able to do. Even now financial conditions would often justify larger expenditures for water purification than are actually made if adequate results could not be otherwise obtained, and the instances where this is the case are sure to increase rapidly as the years go by.



Hydraulic Washing of Dirty Sand from Sand Filters, Washington, D. C.

(Original design.)

Sand Washer and Sand Bins, Washington Filters.

(Improved design.)

It may, therefore, be reasonably anticipated that still more efficient methods of purification will come to be used in course of time, and in discussing the advantages and disadvantages of the use of river and other polluted waters after purification by cities through a long term of years with steadily increasing amounts of pollution, it will not do to consider only the methods of purification now in use. Better methods will be available for the more difficult service when they are needed.

CHAPTER XII.

STORAGE OF FILTERED WATER

FILTERED water is in general to be stored only in covered reservoirs where it is not exposed to strong light. Ground water, which is water that has been filtered by nature in passing through the soil, is to be treated in the same way.

There are many cases where such waters are stored in open reservoirs; in these cases the waters always deteriorate in quality, but not always to the extent of making them inacceptable.

Deterioration takes place principally in warm weather. It results from the growth of microscopic organisms in the water. The mineral food supply (corresponding to fertilizer on a wheat crop) is always contained in the water and in the air. The organisms decompose carbonic acid always present in both air and water, with the aid of the light, and build up from the carbon obtained from it the organic matters of which they are composed, precisely as the wheat plant builds up its structure from inert mineral matters. If time and other conditions permit, the organisms will grow until the water becomes offensive with them, and the products of their growth and decay.

Filtered waters are stored in open reservoirs, i.e., in old reservoirs previously used for raw water, at Lawrence,

Albany, Washington, Watertown, Paterson, Hackensack, and many smaller places. In some cases not much trouble has been experienced; in others, the conditions have been far from satisfactory.

Practically all reservoirs built for filtered water in the last years have been covered, and some old open reservoirs have been covered. This has happened more frequently in the case of ground water supplies than in the case of filtered water supplies.

The advantage of storing filtered waters in the dark, where they will keep entirely without deterioration, is so great that it seems certain that the present practice of covering will be continued until the present open reservoirs are all abandoned or covered.

Covered reservoirs for filtered water have been built at many places. Among them, at Albany, Watertown, Ithaca, Yonkers, N. Y., Washington, D. C., Philadelphia, Pa., and by the East Jersey, Hackensack, Queens County and Superior Water Companies. It should be noted that in many cases there are several reservoirs, some open and some covered in the same city.

CHAPTER XIII.

ON THE REQUIRED SIZES OF FILTERS AND OTHER PARTS OF WATER WORKS.

ONE of the most perplexing questions to a beginner is to find the reasons for the apparent discrepancies in the sizes of the different parts of a well designed water works system. If a system is capable of supplying 15,000,000 gallons per day, it would seem at first thought that all parts should be of this capacity and that nothing beyond it would be necessary. But this condition is never realized. The pumps have one capacity, the pipes another, the filters still another, and the plant is declared to be too small while the average consumption of water is below any of the figures given for the capacities of the component parts.

In laying out a system of works there is no matter which calls for more careful study than the most advantageous sizes of these component parts. To some extent these sizes are not capable of calculation, but are matters of judgment. The judgment to be valuable must be based on extended experience, and must take into account all the particular conditions in the case in hand.

Let us take a particular case to illustrate in a general way the method of getting at these sizes.

The city under consideration has a present population of 80,000, we will say. The works now built should be

large enough so that no addition will be required for ten years. In some parts it may be worth while to anticipate growths for a longer period. The rate of growth to be anticipated is judged from the past rate of this particular city, and of other cities similarly situated, taking also into account any special conditions likely to make it grow either more or less rapidly than it has done, or than its neighbors. In this case we will say that, all things considered, 25 per cent per decade seems a reasonable allowance. Adding 25 per cent to the present population brings us to a population of 100,000, which must be provided for in the first construction.

The amount of water per capita is next to be considered. This depends somewhat upon the habits of the people as to the use of water for domestic purposes, and for watering lawns and streets; somewhat upon the amount of water sold now or likely to be sold for manufacturing, railway, and trade purposes; and still more upon the amount of water that is wasted by takers and the amount lost by leakage from the pipes.

The present consumption we will say is 100 gallons per capita daily. A greater manufacturing use is to be anticipated, but on the other hand, it is proposed to install more meters upon the services which will reduce the waste. This will offset the increase in actual use per capita, and we will consider 100 gallons per capita daily as the probable consumption ten years hence.

The quantity of water to be provided is thus 100 gallons per capita for a population of 100,000, or 10,000,000 gallons per day.

Ten million gallons per day is the average daily

amount for the year. Sometimes the use will be less and sometimes more than the average. There are few cities where the maximum month does not exceed the annual average by 15 per cent. There are some where it is 50 per cent greater. In this case 25 per cent is assumed.

The maximum monthly consumption will thus be 25 per cent above the average, or 12,500,000 gallons per day.

The maximum daily consumption must be taken as 10 per cent more than this figure, or 13,750,000 gallons per day.

During some hours of the day the rate of consump tion is far greater than at other hours. The excess of the maximum hourly rate over the average daily rate is more nearly in proportion to the population supplied than it is to the average amount of supply. In other words, the use of water fluctuates, while the waste does not fluctuate, and where waste is large in proportion the fluctuations expressed in percentage of the whole are less. In this case a rate of 80 gallons per capita is taken as representing the excess of maximum rate of consumption over the average of 100. The maximum rate of use, therefore, will be at the rate of 180 gallons per capita, or 18,000,000 gallons per day.

This does not include the water required for fire service, which must still be added. For ordinary fires which are quickly put out, no very heavy drafts are made. But for the larger fires, which occur at long intervals, a liberal supply must be furnished.

In this case, taking into account the nature of the sit-

uation and value of the property, we assume that water to supply 30 standard fire streams should be available. Such streams use 250 gallons of water per minute, or at the rate of 360,000 gallons per day for each fire stream. Thirty streams will require water at the rate of 10,800,000 gallons per day.

If this was added to the maximum rate of use, 18,000,000 gallons per day, it would give the extreme maximum rate to be provided for of 28,800,000 gallons per day.

Actually there is so little probability of the occurrence of the maximum fire at precisely the time of the maximum use of water for other purposes that we can afford to take a few chances on it, and this figure may be cut somewhat. With an average use of 100 gallons per capita, rates exceeding 130 gallons per capita would not occur for more than a small percentage of the time. This would be 13,000,000 gallons per day. Adding our 30 fire streams, or 10,800,000 gallons per day, to this, we have 23,800,000, or say 25,000,000 gallons per day, as the amount which the works must be capable of supplying when there is demand for it in case of a heavy fire.

It is only necessary to prepare to supply water at this highest rate for three or four hours, but the works must be able to supply water at the maximum daily rate of 13,750,000, or say 14,000,000 gallons per day, when required, for a number of days in succession.

We can now take up the sizes required for the different parts of the works.

If an impounding reservoir and its catchment area are sufficient to maintain a constant supply in a dry year equal to the annual average contemplated use, that

will suffice. The reservoir will take care of fluctuations in the rate of draft, and no computation need be made of the effect of such fluctuations.

The pipe line leading from the impounding reservoir to the distributing reservoir near the city must have a capacity equal to the maximum daily use of 14,000,000 gallons per day, or 40 per cent above the average annual use

The hourly fluctuations will be balanced by the distributing reservoir. The storage capacity required to balance the fluctuations of ordinary use will be about 15 per cent of the average daily use or 1,500,000 gallons. In addition to this, enough capacity to maintain the maximum fire draft for four hours should be added. This will require:

$$\frac{4}{24}(25 - 10) = 2{,}500{,}000 \text{ gallons capacity.}$$

This makes the required capacity of the distributing reservoir 4,000,000 gallons per day.

It is not usually convenient to so operate a plant as to keep the distributing reservoir always full, and a fire might occur when it was somewhat drawn down. To provide for this a further allowance should be made, bringing the capacity to 5,000,000 gallons, or one-half a day's average supply. And if the fire risk is large, the site suitable, and the financial conditions warrant it, a larger reservoir, up to at least a full day's supply, will be safer and better.

Purification works and pumps, if used, located between the impounding reservoir and the distributing reservoir, must have capacities equal to the maximum day's use,

and, in addition, reserve units or capacity must be provided to cover the time lost in cleaning filters and in repairing pumps; and it is customary to have a reserve unit of each kind, so that the supply would not be crippled by having one pumping or filtering unit out of service for some time.

As a general rule, where the distributing reservoir balances hourly fluctuations and provides for fire service requirements, the filters should have a capacity a half greater than the average rate of consumption, and the pumps should have a nominal capacity twice as great as the average rate of pumping.

The average rate of the filters will thus be two-thirds of the maximum rate, and the pumping machinery will operate equal to one-half its nominal capacity when the capacity of the plant is reached. At all other times the ratio of use to capacity will be less.

The pipes from the distributing reservoir to the city, and through it, must have a capacity up to the maximum rate of use of 25,000,000 gallons per day.

If the water is pumped from the reservoir to the city, the pumps must have this capacity with one unit in reserve. This means practically that the pumps for direct service must have a capacity equal to three times the average rate of use. In small works the pumps must be even larger than this in proportion.

It never pays to build filters and purification works to meet the maximum rate of consumption. Even in case of a river supply and direct pumping of the filtered water into the distribution pipes, it pays to provide a pure water reservoir at the filters to balance the hourly fluctuations

in rate. This permits the purification plant to work at a constant or nearly constant rate throughout the twenty-four hours, which is advantageous.

The figures used in this illustration are representative, but there are reasons in particular cases why higher or lower values must be used. But in every case there are certain ratios that must be met. With pumps capable of lifting 10,000,000 gallons per day, and filters capable of filtering, and pipes capable of carrying this quantity, it has never been possible, and it never will be possible, to deliver under the required conditions of practical service 10,000,000 gallons of water per day, nor even an approximation to this amount.

This matter, although very simple, is mentioned at length because it is one of the most common matters to be misunderstood, and a perfectly clear understanding of it is essential.

Some most important projects have been seriously defective and incapable of their supposed capacities because of inadequate allowances of this kind.

CHAPTER XIV.

AS TO THE PRESSURE UNDER WHICH WATER IS TO BE DELIVERED.

IN considering source of supply, the question of the elevation of the source and of the distributing reservoir is often an important matter, as it concerns the pressure under which water is or might be supplied.

In the older American water works only very moderate pressures were used. In New York, Boston, Philadelphia, Washington, and a hundred other cities the works were laid out so that with reasonably satisfactory piping, water was available in the highest stories of the houses that were common at that time, or, in a general way, in houses three or four stories high. The works were further generally arranged to maintain this pressure only in those parts of the cities which were comparatively low in elevation, those parts at the time having contained most or all of the houses for which public supply was regarded as necessary.

The elevation of the reservoir once fixed for a certain service and pressure, it is by no means an easy matter to change it, and the elevation and pressure thus established many years ago have been in most cases maintained to the present day, even though the conditions have so far changed that if new works were now being laid out, the arrangements made would certainly be very different from the actual ones.

Occasionally where new or additional works are laid out, there is an opportunity to change the conditions in this respect. Such change nearly always involves the abandonment of some old structures, especially reservoirs that are too low for the new conditions; and sometimes old pipes not strong enough to stand the new pressure. Changes in pumping stations may also be involved, or the construction of new ones.

The reasons for and against such changes must be carefully weighed. But in many cases the old conditions are so thoroughly inadequate, that radical and expensive changes are desirable and necessary.

The tendency of the times is clearly to the use of much higher pressures.

Higher pressures are desirable for a number of reasons, among them the following:

(1) Buildings are in general much higher than a generation ago. Practically all of the higher buildings in the above mentioned cities, and in many others, find it necessary to install pumps to lift the water to tanks on their roofs, from which the supply in the building is maintained. In New York City alone many thousands of buildings are obliged to maintain their own pumping plants and tanks. The aggregate cost of installing these private supplementary works, and of operating them, is very large. If the city could increase the water pressure in the mains so as to make these private works unnecessary, this cost would be saved to the citizens, and the saving so made would probably greatly exceed the cost of increasing the pressure of the public supply,

even though that involved, as it would, many new, extensive and costly works.

(2) Cities in growing have extended to higher land than that originally occupied, and for such higher areas the service is particularly deficient. In many cases such higher areas are left to get on as best they can with the pressure that is available. When they are so high that such service is entirely inadequate, separate high service systems have usually been installed. That is to say, such areas are supplied by an entirely separate system of pipes, and water is pumped or otherwise supplied to them at a higher level or under greater pressure than is used in the main service.

Many areas are so high above the lower part of the cities that separate high service districts are really necessary, but there are many other cases where the areas could be supplied satisfactorily from the main service if the pressures in the older and lower parts of the cities were increased to the points which would be most advantageous for them on their own account. In general, it is best to keep the pipe systems as simple as possible, and to avoid separate high service systems where the service to the higher districts can be reasonably maintained in another way.

(3) Higher pressure is desirable for fire service; that is to say, for use in putting out fires. There are very wide differences in the capacities of different water works systems for this use. In European water works practice, owing principally to the less inflammable nature of the buildings, but little provision is made for fire service. The water pipes are provided to distribute

the water from the source to all the points where it is taken, and in the quantities needed for ordinary requirements. Some provision is made for anticipated growth, and allowance is made for fluctuations in rate occurring in the different hours and minutes of the day; but in general the pipes are small in size, especially the lateral pipes, which are often as small as four, three, and even two inches and less in diameter.

Some early American water works were laid on this plan, but it is to be found now in general only in small villages which have grown very slowly, most of them having spring water supplies. Such supplies do not furnish much fire protection. Buckets of water may be obtained to put out a starting fire, but no effective fire stream from a hose can be obtained to put out a fire already under way.

The first step in providing fire service is to arrange the pipes so that a supply of water to fire engines or pumps can be obtained from them. To do this requires the provision of a reservoir or pumps to deliver water to the pipes at a greatly increased rate in case of fire, and increasing the sizes of the pipes above the sizes required for ordinary service to such an extent that the required quantity for fighting a fire in addition to the usual flow can be taken from hydrants in any part of the city.

This result is more easily obtained where pipe lines are cross-connected into a "gridiron system," as is now customary. By this means every pipe is reinforced within a reasonable distance by a number of other pipes, and the quantity of water that can be drawn from it is correspondingly increased. With the fire engine system

no effort is made to supply water for fire service under pressure sufficient for direct use without fire engines, and there is therefore no need of raising the pressure on the whole system because of the fire service to be obtained from it. The pressure required to throw streams of water on to the fire is all obtained from steam fire engines connected with the hydrant or hydrants nearest to the fire.

Years ago four-inch pipe was laid in water works systems, to be used in this way; but this proved inadequate in practice, and the minimum size now used is six inches in diameter. In New York City, the minimum size now laid is eight inches, and in districts of large, inflammable buildings the minimum size is still larger. This arrangement, with modifications here and there, is in use in Boston, New York, Philadelphia, Washington, and most of the older cities supplied by gravity from reservoirs, at relatively low elevations.

The next step in fire protection is that known sometimes as the Holly system. This is used only for supplies which are pumped, and is commonly used in the smaller cities of the Middle States. Pumps are provided of a capacity greatly in excess of the ordinary use, and built to produce a pressure much beyond that needed for ordinary service. Ordinarily the pumps are operated slowly, and only a moderate pressure is maintained. Extra boilers are kept with steam up, and in case of an alarm of fire the pump is at once speeded up to give an extra volume and an extra pressure. The pressure is commonly increased to the point where the hose can be attached to hydrants and good fire streams obtained directly from them without the use of fire engines to

further increase the pressure. A pressure of 70 pounds per square inch at the hydrant is regarded as about the minimum for this service, and to secure this, even in perfectly flat country, a somewhat greater pressure at the pumping station must be carried to cover the loss of head by friction in the pipes. Pressures of one hundred pounds and over are common. More pressure is needed if the buildings to be protected are large and high. In this system the pump at the water works station does the work that would otherwise be done by the fire engines.

This system works well in small towns where fires do not occur often. In large cities, with frequent fire alarms, the disturbances from fluctuating pressure would be too great, and the system is not used.

At Chicago, Detroit, etc., where direct pumping and no reservoirs are used, the increased rate of draft is taken care of by the pumps, but no effort is made to increase the pressures during fires so as to allow direct fire streams to be used. Fire engines are always used to give the additional pressure required.

The next step in giving more fire service is the maintenance at all times of pressure in the pipes high enough for fire service. When this is done, every fire hydrant is just as good as a fire engine up to the capacity of the pipes. This system has been adopted, especially with gravity sources of supply high enough in elevation to maintain such a service without pumping. Such supplies are often in hilly country, and the pressures in different parts of the area served may vary greatly. Full fire service may be maintained on the lower levels, and less adequate service supplemented by fire engines may be used on the

higher levels. As the largest buildings are usually upon the lower levels, this arrangement works very well. Among the cities having such comparatively high pressure are the following:

Place.	Extreme maximum pressure, pounds	Maximum pressure over a considerable area, pounds.	Ordinary minimum pressure, pounds.
Fitchburg	170	...	75
Syracuse	100	90	60
Westfield	...	115	65
Springfield	145	140	70
Worcester	170	125	70
Newark	165	...	...
Peekskill	...	158	158
Kingston	140	...	65
Fall River	130	...	80
Providence	120	114	65

There are some disadvantages of high pressure, real and supposed:

Where the water is pumped, the cost of pumping is increased. This is a question of cost, and the cost can be computed.

Increasing the pressure tends to a greater waste of water. If all the openings remained the same, the water waste would increase as the square root of the average pressure. Multiplying the pressure by four would increase the waste by two. For a comparatively small increase, adding two per cent to the pressure would add one per cent to the amount of waste. Actually the increase of waste is not in this proportion, for leakage from a pipe under higher pressure makes more noise and is more easily discovered than leakage from a pipe under

lower pressure, and it is therefore more likely to be discovered and stopped.

Formerly there may have been difficulty in providing pipes and plumbing to stand successfully as high pressures as may now be considered. But there is no trouble in securing pipes and fixtures to do it now. An increase in pressure may be somewhat destructive of some old plumbing, but pressure reducers can be put on to individual houses to avoid this with considerable success; and in any new work the additional pressure is not objectionable, and does not increase the cost of properly designed plumbing. Better work is required, but the sizes may be smaller.

In recent years a great many cities have installed special high pressure services for fire use These are usually entirely independent of the ordinary water supply, and they are mentioned here briefly only for completeness. In several cases salt water is used for this service. Otherwise, river or lake water is taken at the nearest point, regardless of quality. Pressure is only kept up when needed.

In other cases the high pressure water is from the same source as the ordinary supply, and the fire pressure may be constantly kept upon the special pipes if it is a gravity supply. This last arrangement has the advantage of allowing especially high buildings to be supplied from the high pressure pipes, and it is not unusual for the same system of pipes that supplies extra pressure downtown to extend to and supply at ordinary pressures parts of the city upon higher land. In other words, the pipes from a high service district are simply extended through

a low service area having special need of high pressure water. Newark, Worcester, Fitchburg, and other cities have this arrangement.

American cities are built in a way to make them more subject to damage by conflagration than those of any other country. The abundance of wood in the past, and the cheaper construction with it as compared with other building materials have had much to do with this. There has also been far too little attention paid to building in a way to make serious fires impossible.

Most of the buildings now being erected are better in this respect. Each modern steel building, with fire-proof walls and floors, erected in place of an old building with wooden floors, reduces the chance of conflagration. A bad fire cannot start in such a building; and if one starting outside burns to it, it tends to act as a barrier to the fire and stop its progress.

With rebuilding going on at its present rate, the fire conditions in our cities will improve, until ultimately the requirements of fire service upon the water works system will be reduced to an approximation of what they now are in European cities. That is to say, it will only be necessary to provide pipes for the distribution of water for ordinary purposes, with a comparatively small addition for fire requirements.

But that day is a long time in the future. At the present time we are using vast numbers of buildings that are anything but fire-proof. These buildings on the whole are good and useful, and must continue to be used for many years; and so long as they remain, water works systems must be planned and built and used to protect

them. The property that may be lost in a day through failure of water in a San Francisco or Baltimore fire will pay for very generous additions to the pipes and pumps and reservoirs in many cities.

Under present conditions there can be no doubt that far better fire protection would pay in many or most American cities, and it is well worth while to secure it. But the certain ultimate improvement in building conditions, that is to say, the gradual elimination of fire-traps and the substitution of buildings that are fire-proof, or nearly so, must be kept in mind in planning for works to serve for long periods.

CHAPTER XV.

ON THE USE, WASTE, AND MEASUREMENT OF WATER.

THE quantities of water supplied in a number of American cities are as follows:

Place.	Year.	Gallons Per capita daily.	Percentage of services metered.
Buffalo	1912	334	5
Chicago	1911	235	4
Pittsburgh	1910	235	11
Philadelphia	1911	202	4
Detroit	1910	177	10
Washington	1912	175	3
Boston	1912	125	35
Cincinnati	1911	125	48
St. Louis	1911	118	7
Cleveland	1912	113	98
Milwaukee	1912	113	99
Newark	1911	107	54
Louisville	1911	105	7
New York	1912	104	25
Minneapolis	1912	81	59
Worcester	1911	68	97
Hartford	1911	66	98
Providence	1911	65	89
St. Paul	1911	60	53
Lowell	1912	50	82
Lawrence	1911	46	92
Fall River	1911	44	99

The quantities of water supplied in a few European cities are as follows:

Place.	Year.	U. S. Gallons per capita daily.	Place.	Year.	U. S. Gallons per capita daily.
London....	1908	41	Berlin......	1909	22
Liverpool....	1912	44	Hamburg...	1910	81
Paris........	1901	65	Dresden....	1909	26
Amsterdam .	1905	37	Copenhagen	1909	29

And in Australia:

Place.	Year.	U. S. Gallons per capita daily.	Place.	Year.	U. S. Gallons per capita daily.
Melbourne.	1905	63	Brisbane	1906	58
Sydney . .	1905	39			

Taking it right through, probably one-half the water supplied to American cities is wasted. Some of this waste is unavoidable, but the greater part of it could be stopped.

Because of this great waste of water the cost of the works is increased, and likewise the cost of maintaining them.

The increase in cost is not as rapid as the increase in quantity of water, but it is substantial. Probably the whole cost of supplying water in America is from a third to a half greater than it would be with the reasonable suppression of waste. In some cases the ratio is much greater.

If the policy of Buffalo and Chicago is to be followed in allowing everyone to take and waste water as freely as he likes without paying for it, then the source of

supply and other parts of the works must be provided with a capacity four times as great as where the policy of Worcester and Hartford, of making each one who draws water pay for the amount drawn, is followed.

The advantages of putting a meter on each service and collecting water rates according to its indication are so great and so obvious to all who have studied the water question, that this system promises to become universal in America at no remote date.

When this happens such preposterous conditions as securing and pumping at great expense 250 gallons for each man, woman, and child of the population, of which amount four-fifths, more or less, is lost by leakage absolutely without benefit to anyone, will cease to exist.

On the other hand, it must not be forgotten that in America water is a relatively cheap commodity, and it is likely to remain so, and people will not limit themselves closely in its use. Wealth is increasing; we live in larger houses, have more bath tubs and other fixtures and use them oftener; generous lawns and wide streets need water to keep them presentable, and at fair prices it can be easily afforded.

Let our aim be a generous use of water, but no waste, and each man to pay for what he gets.

It is idle to attempt to ascertain what the per capita consumption for any city in the future will be. To forecast it roughly for a few years is all that need be done or can be done. The water resources of the country are enormous, and they must be developed gradually as there is need of them, and it is the clear duty of the water departments and water companies to develop them as they are needed.

In some cases where unrestricted waste has been permitted, large reductions are possible by changing the methods of sale; but in many other cases there will be increases as people use more water and are willing to pay for it. It is clear that per capita consumptions as low as those in some European cities are not to be anticipated or desired in America. The tendency is the other way. The European figures are steadily increasing, even where all water is sold by meter.

Meter Rates and the Sale of Water. Much of the unfortunate and ignorant opposition to the use of meters has been caused by unreasonable and unjust methods of charging for the water passing the meters. There has been the greatest diversity in these methods of charging, but the underlying principles that should govern are being slowly worked out, and improvements in schedules of charges for metered water are slowly but surely being made by the water departments of the country.

The price at which any commodity is sold will normally be found between two limits. It will not be less than the cost to the seller to produce and deliver, nor will it be greater than the value or utility of the product to the buyer. Water is a commodity and its price is governed by these limits. When the works are owned by a city there is a strong tendency to ignore the second limit and to reduce the price to the first limit, or in other words to sell the water at cost.

In general, this tendency will control, but it does not seem necessary that it should do so to the exclusion of other considerations in all cases. One man gets more comfort or makes more profit from a thousand gallons

of water than his neighbor. If the difference can be ascertained and measured, there would seem to be no reason why it should not be taken into account in fixing the rates. Of course, the practical difficulty is in ascertaining such differences, and this difficulty will greatly limit the use that can be made of the relative value of the service to the taker, but in some cases use may be made of it.

It may be noted that manufacturers and railroads are not slow in representing to water departments that their business will not stand existing rates, or that other supplies can be more cheaply obtained, and on such grounds asking for reductions in charges. And these reductions are frequently made usually because the business is needed, and is acceptable to the water department even at a reduced rate. On the other hand if a water department renders a service which is especially and unusually advantageous to someone, as often happens, there would seem to be no reason why a charge should not be made greater than where only the usual benefits result from the service.

This matter aside, the problem presented is briefly this: a certain quantity of water is dispensed for all sorts of purposes, and a certain sum of money is to be raised to meet the needs of the department. How can the takers be most fairly taxed to produce the required revenue or a reasonable approximation thereto?

In the first place, the amount to be raised is to be divided into two parts, namely, a first part, including all expenses and capital charges, the amounts of which are dependent upon the amount of water supplied; and a

second part, including all other charges and expenses, which are those not dependent upon the amount of water supplied.

This division can be made only approximately. Making it is a question for the accountants, and the different items in the total schedule of payments made in a year must be carefully looked over to see how far each would be affected by a change in the quantity of water supplied. There will be plenty of room for discussion as to many of the items, and only a rough approximation need be attempted. It may even be made arbitrarily by assuming that one-half or one-third of the total expense is not affected by the quantity of water supplied.

Having separated our schedule into these two parts the first part is to be taxed upon the water according to volume; the second part is to be taxed upon the fixtures and property according to rules to be adopted.

If all the water went through meters, and if the meters recorded it all, the first sum divided by the quantity of water supplied in a year would be the rate that would have to be charged for all water to produce the required revenue; and there would seem to be no adequate reason for, nor justification of, a sliding scale as it is called, that is, of a schedule by which small takers pay more in proportion than large ones.

The calculation has sometimes been made in this way, when only a part of the water has been metered, but it will not work out with all the water metered, and for this reason it is unjust when only a part of it is metered. There are two reasons for this: first, some water is lost by leakage from the pipes before the meters are reached

and never passes through them; and second, the meters practically always pass more water than they record.

When water passes a meter rapidly it is recorded with considerable accuracy, but when it flows through slowly some of it leaks around the moving parts, and the amount registered is below the truth. This is especially the case with meters that have been worn by use, and the meters of a city, as a whole, register a smaller proportion of water passing them than is shown by the usual shop tests of meters even when these tests are made at low rates of flow.

Meters wear less rapidly when the water is perfectly clear filtered water or ground water than where river and other surface supplies are used.

Under present American conditions it does not seem possible to make the meters account for more than from 50 to 70 per cent of the supply. This shortage does not all come from the slip of the meters. Some of it is from the leakage from pipes.

There is reason to believe that the proportion of water accounted for will be gradually increased with better conditions. Some German cities do much better than this in accounting for their water at the present time.

If the amount that can be accounted for is not known by actual experience for the works in question, then the calculations should be made on the basis that 60 per cent of the water, or thereabouts, will be actually charged for, and that this amount will produce the full sum to be raised in this way.

The assessment of the second part of the amount to be raised, that is to say, the part that is not affected by the amount of water that is used, presents greater difficulties.

In studying this division two thoughts should be kept in mind. First, the amount charged in this way on each service should not be less than the sum that will serve to maintain the service and the meter upon it and pay the cost of reading the meter and of the proper proportion of the bookkeeping and general expenses which are in no way affected by the amount of water that is used. Second, the amount to be raised in this way may, with propriety, be charged to some extent, according to the value of the service to the taker, as far as that can be determined by a simple and sure method of calculation. All property is more valuable because a good water service is available and quite apart from the amount of water that is used, and there is no reason why some payment should not be made to the water department because of this element of value in the service.

The simplest way of apportioning the sum to be raised in this way is to divide it equally among the services. Berlin, Germany, collects twelve marks, equal to about three dollars per annum, for each service, and in addition collects payment for all water recorded by the meters. Milwaukee has similarly collected one dollar per annum for each service, but this is clearly too low a figure. It will not pay for the maintenance of the services and meters.

A better way is to base the payments upon the size of the service. Most of the services of a system are domestic services, that is to say they serve residences. These services are commonly five-eighths of an inch in diameter. The assessment on these may be placed at $3.00 per annum, let us say. Some takers insist on a larger ser-

vice because they wish to draw water more rapidly. Many discussions take place because the prospective taker is insistent on a larger service, while the water works superintendent believes the usual size to be sufficient. Why not let the taker have a service as large as he likes and charge him for it in proportion to its size, or, let us say, approximately in proportion to its ability to deliver water?

Starting with a charge of $3.00 for a five-eighth inch service, and using round figures, the charge for larger services, not including the charge for water would be

For ¾-inch	$5.00	per	annum
For 1-inch	10.00	"	"
For 1½-inch	20.00	"	"
For 2-inch	30.00	"	"
For 3-inch	70.00	"	"
For 4-inch	125.00	"	"
For 6-inch	300.00	"	"
For 8-inch	500.00	"	"

This arrangement has the practical advantage of making a substantial charge for a substantial service, and for a service that too often is not adequately paid for, where large pipes lead from the mains into mills, warehouses, etc., for fire purposes only, and from which pipes ordinarily no water is drawn.

These pipes cause more trouble to water departments, and the privileges granted are subject to more gross abuse, than those from any other class of service; and it is right and proper that substantial payments should be made for them.

Such large fire services should always be metered and they should not be allowed to exist on any other condition. This has not been possible until recently, but

it can be done now, for a type of meter has been invented which is satisfactory from a water works standpoint, and which does not interfere materially with the value of the pipe for fire service. With this meter the water ordinarily passes through a by-pass on which there is a small meter. But in case of need, that is in case of fire, a valve on the main line opens automatically and the full quantity of water that the pipe will carry flows through it unobstructed for use. Even in this case an approximate idea of the amount of water drawn is registered by some extremely ingenious devices which are only brought into play when the main valve is opened.

The general idea of charging in proportion to the areas of the service pipes has been expressed in the form of minimum rates at Cleveland and other places. I do not know that it has been followed anywhere to its logical conclusion, as above outlined.

Another way to divide the sum to be taxed on services is in proportion to fixture rates. This method is applicable especially in cities which are gradually changing from fixture charges to the meter system. In this case the fixture rates are known for each house. Supposing it is decided to assess one-third of the whole amount to be raised upon fixtures then when a meter was installed on a given service the charge for that service would be one-third of the previous fixture rate, and in addition all water used would be charged for.

For these conditions this system has much to recommend it. But it is a transition system. When all services are metered it is not to be supposed that it will be worth while to continue making fixture rates. A more

simple method of computation will be demanded and should be used. This can be brought about without the slightest trouble, and without any radical change when all services are metered.

In England the charge for water is commonly based on the rental value of the property supplied. People living in expensive dwellings pay more for their water than those living in cheaper ones. It would not be unreasonable in fixing the amounts to be assessed on fixtures to take into account either the rental value or the selling value of the properties; but this idea so far as I know has never found expression in American schedules. In New York and a few other cities the width and height of the house are taken into account, but not the value.

There is another point that might be taken into account with reference to fire service. Water works cost more to build and maintain because there are so many inflammable buildings requiring large volumes of water instantly available for their protection in case of fire. Other buildings are being erected in rapidly increasing numbers, so little inflammable that only small volumes of water are needed for their protection. Why should fire-proof buildings pay as much as fire-traps toward the excess cost of the service?

It might not be possible to apply this to domestic services, but it certainly could be applied to connections made specially for fire purposes. If the price computed in proportion to areas is taken as the standard, and applicable to slow-burning well protected mill construction, then why not reduce the charge to one-half for thoroughly

fire-proof buildings, and double it for old and dangerous buildings? Or within certain limits the charges might be based upon the fair insurance premiums paid on fully insured property.

There are so many considerations that might fairly be taken into account that it will be found impossible to make a schedule recognizing all of them and at the same time sufficiently certain and simple to be satisfactory in practice. For a schedule of rates must be easy and certain in application, readily understood by the public as well as by the registrar, and it must not be frequently or arbitrarily changed.

Practically the best way to handle the matter is to devise a schedule based on calculations of the general nature indicated above, and computed to yield a revenue of 10 per cent more than is actually required. This excess allowance is made because there is always some uncertainty as to the effect of changing rates upon the revenue to be produced; and it is better to raise somewhat too much revenue rather than to fall short.

This schedule should be simple and certain, and all figures should be expressed in round numbers. For instance, if the calculation came that way, the figures given in connection with the different sized services might be used and in addition seven cents per thousand gallons for all water used. If this was estimated to yield 10 per cent more revenue than required, there would be a chance of falling below expectations by this amount without embarrassing the department, while under other conditions the revenue might exceed that required by 20 per cent or more.

In the case of an excess of revenue being demonstrated, the charge for water could be reduced to six cents or to five cents as the business would stand, or the charge for services might be lowered. Practical experience with the general method would be available to indicate where the cuts could be best and most equitably made.

The use of a sliding scale, that is to say, or making lower rates to large takers, is firmly fixed, and it will be hard to do away with the idea. But the writer believes that such a scale as that suggested contains all the provisions of this kind that are necessary or wise.

In the first place this kind of a scale is in reality a sliding one. The small cottage pays, let us say, $3 per year for the service, and in addition uses water charged at $0.10 per 1000 gallons, let us say, amounting to $3 per year in addition. The total payment is $6 per year and the average cost of water to the taker is $0.20 per 1000 gallons.

A larger taker pays, let us say, $12 per year for his service, and uses at the same rate water worth $120 per annum. The whole bill is then $132 and the average cost of water to him is $0.11 per 1000 gallons, against the $0.20 paid by the smaller taker.

The basing figures of course are to be fixed to meet local conditions, and when so fixed they will give all the slide that is desirable. There is no reason why the man in a cottage, who lets his plumbing get out of order and wastes an extravagant quantity of water, should be asked to pay a larger price per thousand gallons for the water

wasted by his neglect than is paid by the largest establishment.

Manufacturers are often supplied by cities at special rates which are less than cost. This is most frequently done on special pleas, and is comparable to giving exemption from taxation. The practice is not a wise one and should not be encouraged.

Low rates are also often made to secure customers who would not otherwise use water or who would not use so much. This is most apt to be done in the early days of operation of a system when the capacity of the works built in anticipation of growth is beyond present requirements. Hydraulic elevators and motors are most common and objectionable subjects for such special rates. As long as the capacity of the works is really in excess of the demand, a little financial help is received by the department from such rates; but as soon as the capacity of the plant is approached such rates become a drag and a source of loss. Experience shows that they are not, and cannot possibly be shut off promptly when they cease to be profitable. It is, therefore, better and safer to charge the regular rates for water used for these and all other special purposes, and to take good care that all water so used is paid for. Some revenue will be lost; some elevators and printing presses will be driven by electricity instead of by water power, but electricity is a better way of transmitting power than water under pressure, and in the end all will be better off.

American cities having high service systems make precisely the same charges for water from them as for

water from the low service pipes. The man on the top of a hill with high service water pays no more than the man in the valley, though to supply him costs the city usually from two to five cents more per thousand gallons, and where the high service districts are small and isolated the extra cost may greatly exceed these figures. There seems to be no well-founded reason for this equality in charge with clearly defined difference in cost of service.

It would seem rational and wise to charge more for high service water than for low service water, and to establish the differential carefully at so many cents per thousand gallons, to pay as nearly as it can be computed for the additional cost of the high service water; and the differential should be subject to revision from time to time as the conditions of service change. Usually it would be higher at first, with few takers, and less as the quantity sold became greater.

The present method is unfair to those on low ground. They pay their share (usually the largest share) of the excess cost of supplying water to those located on the hills. And this is the more unfair, as the hill sites are usually more desirable for residences, and those who live on them are well able to pay the added cost which their service entails on the water department.

I have described this meter rate question at some length, because I feel strongly that present methods of charging are in general unfair and unreasonable, and because I believe that the adoption of the general principles here outlined will do a great deal to improve the situation.

The sooner arbitrary and unreasonable methods are abandoned, and more reasonable methods are adopted, the better it will be for both consumers and for water departments, and the easier it will be to supply clean water and to make the financial arrangements for doing it.

CHAPTER XVI.

SOME FINANCIAL ASPECTS.

IN America water works receipts average about \$2.50 per capita for the population supplied, but figures ranging all the way from \$2.00 to \$4.00 are common, and some figures are outside of this range. These are for publicly owned works. Private companies average to make about the same collections for domestic rates, and in addition they are paid for fire service, so that their total receipts average about \$3.00 per capita. Publicly owned works as a rule receive no separate payment for fire protection.

There seems to be no well marked tendency to either higher or lower collections per capita in the larger cities, as compared with the smaller ones. Large cities usually have to go farther for water. Small sources near at hand are not available to them, and it would seem reasonable to suppose that the relative cost would be greater. But it seems that the savings which are made by operating on a larger scale offset this tendency, and on the whole, the expense of securing water is just about the same on an average in proportion to population in small cities and in large ones.

In Europe the per capita cost of water is rather less. In London where the works of eight private companies were turned over to public ownership in 1903, and where

the rates charged by the companies continue practically without change, the collections amount to $2.00 per capita, which does not include any separate payment for fire service.

Paris collects about $1.50 per capita, and this seems to be also about the average amount collected in English cities, excluding London, under public ownership. In other European cities, as far as returns are available, the collections do not average more than about $1.50 per capita.

In Australia the collections seem to be nearly up to the American average. But little fire service is provided, but the population supplied is scattered, necessitating rather great length of distribution piping. The per capita quantities of water supplied are not high, but the cost of securing the water is relatively high.

In arid districts the per capita cost of water works may be increased almost indefinitely with the increase in value of the water to the takers and in the cost of securing it.

In comparing American with European conditions, it must be remembered that, in general, a much larger expenditure has been made in Europe for the purpose of improving the quality of the supplies, and, on an average, the qualities of the waters actually supplied show the effect of this expenditure and are better than American waters. On the other hand, the American works have been built at considerable additional cost to enable them to supply water rapidly in case of fire, a condition which, in general, does not exist in Europe because of the less inflammable character of the buildings; and

the additional cost of the larger pipes and reservoirs to meet this condition in America may be as much as the additional expenditures for quality in Europe.

Labor is cheaper in Europe, but probably the number of men employed is enough greater to offset the effect of the lower wages paid.

The principal element of difference is in the quantity of water supplied. American cities on an average probably use two or three times as much water per capita as European cities, or, more correctly, they waste so much as to produce these ratios in the amounts supplied. It certainly seems reasonable that to supply two or three times as much water per capita the cost of the service would be increased by 60 per cent.

The disposition of the $2.50 per capita collected on an average in America is about as follows: First, in works where the supply is from a gravity source, and no purification is used, about $0.50 per capita annually is used for paying the general expenses of administration, of taking care of services, meters, etc., of making repairs, and of maintaining the works generally. The $2.00 remaining pays 4 per cent interest, and 1 per cent depreciation, or together 5 per cent capital charges on a cost or value of works averaging $40 per capita. The $40 is about equally divided between the distribution system, which includes the pipes in the streets of the city, the services, meters, etc., and the source of supply, which includes all the works for securing the water and bringing it to the city.

Second, in works where the supply is pumped from a river or lake near at hand, with or without purification,

about \$0.50 is used for the general expenses as above mentioned. Another \$0.50 is used for pumping and purification (rather more when the water is purified; less when it is not); and the remaining \$1.50 pays 5 per cent capital charges on an average investment of \$30 per capita, of which \$20 is in the distribution system and \$10 in the source of supply.

Gravity sources of supply cost more to secure, but are cheaper to operate.

The above mentioned figures are general approximations, given to show general water works conditions in America at the present time, but wide fluctuations will be found in individual cases.

Some cities are so located that no good, adequate source of supply is near at hand; and where water is brought from long distances and is pumped and purified, it is clear that it cannot be delivered at the cost or sold at the price that is fair for a water drawn from a pure and ample source near at hand.

Then the cost of distribution differs. In a city on level ground where one service or one system of pipes does for all, the cost both of construction and of operation is less than on a hilly site where separate high service districts must be maintained, involving additional pipe systems and additional pumping stations. And a city that is compactly built up, so that it can be served with a pipe system having a mile or less of pipe per thousand of population, can be more cheaply served than a scattered city with long lines of pipe running out where there are but few houses, and where, taking it right through, two or

even three miles of pipe are required per thousand of population.

Cities that waste large amounts of water have to pay for it. The cost of the works is greater, and this cost is sure to be represented sooner or later in the assessments.

Matters of these general natures largely explain why some cities can be supplied for less than $2 per capita while others must collect over $4 per capita.

The service of water is one of the cheapest. The average American family pays far more for gas, for ice and for milk, than for water. In my own household in New York, taking the cost of Croton water at $1, the average cost of other household supplies is as follows: Ice $3, Light $4, Telephone $5, Coal $13, Milk $15. Taking into account the nature of the water service, which has become absolutely indispensable, the low cost is very remarkable.

Rather than not have it, a city like New York could afford to pay without hesitation ten times the present water rates; and such rates would be paid if there was necessity for them, as happily there is not, and never will be.

Some interesting computations indicating the enormous value of pure water to the inhabitants of a city have been recently published.[1] I shall not repeat them here, but will only call attention to one well known and highly significant fact. When the inhabitants of an American city get the idea, rightly or wrongly, that the water of the public service is not good to drink, many of them proceed to supply themselves with drinking water in other

[1] The Value of Pure Water; G. C. Whipple; John Wiley & Sons.

ways. *Filters of greater or less efficiency are installed in thousands of houses, and bottled spring waters find* an extended sale at prices which represent handsome profits to the venders. Such sales of spring water may be brought about by the turbidity of the water, or by its color, or by tastes and odors, or by iron in it, or by deficiency in hygienic quality, and the supposition, often well founded, that disease may be produced by it.

It is difficult or impossible to ascertain even approximately how much money is spent for spring water; but in some cases partial returns of a reliable nature indicate that the payments for spring water by the relatively small number of people who can afford it, are equal to twenty per cent or more of the gross revenue of the water department. This ratio of expense for spring water probably is not uncommon in American cities, and there are probably some cases where it is greatly exceeded. In the homes of the wealthy the spring water bill may be many times larger than the charge for the water of the public supply.

I cite this condition merely to show the value which that part of the public which can afford it puts on good water, as measured by its willingness to pay cash for it.

Now there is hardly a city in America supplying bad or inferior water at the present time which could not substitute a new supply, or purify the present one, no increase of quantity being made, at a total cost representing less than twenty per cent of the water rates; and in many cases this could be accomplished for ten per cent of those rates, or even less. And this is with reference to a new or improved supply so free from hygienic

objections, turbidity, color, and all other objectionable qualities, that there would be no reason left for resorting to spring water.

Such a standard of purity is clearly within the reach of all cities at this time. There is no good reason why a lower standard in any particular should be accepted.

And in many of our cities an amount of money sufficient to bring the whole public supply to this standard, if it were so applied, is spent by the relatively small number of well-to-do people who can, or think they must, afford it for spring water, which spring water is not of better quality, and is often of far worse quality, than that to which the public supply for all the people might reasonably be brought.

It is unnecessary to develop this matter further. There is no uncertainty about it. Only one conclusion can be reached. The American people ought to have for their public supplies water substantially equal in hygienic quality and in physical appearance and attractiveness to the best spring water. Such supplies can be secured. Sometimes water of this quality can be secured naturally; at other times by artificial purification. The means to be used for accomplishing this end are well known. The costs of carrying them out are reasonable. The advantages of pure water are worth far more than the cost of securing it.

The service of water to the public as the business is now conducted is a very cheap one. The people could afford if necessary to pay far more than they now do for good water; but fortunately in most cases no great

increase in the cost of the service need be made to secure it.

There is not the slightest doubt that the American people will more readily and cheerfully pay $4 per capita for an adequate service of pure, attractive water than they will pay $2 for an inferior service, while the difference in cost of maintaining the service will never be as great as this.

Under these conditions the plain duty of the water departments and of the water companies of the country is, first, to provide a thoroughly adequate service of pure water and of attractive water; and second, to fix the water rates so that this service can be paid for by them.

At the present time there are many laws, ordinances, debt limits, and bonds outstanding, which limit action and prevent the immediate following of this policy. But where there is a general determination to secure a result, it can be reached, and a better understanding of the conditions by those who make and repeal the laws and ordinances, and are responsible for other arrangements, is the first step in bringing about the desired conditions.

CHAPTER XVII.

THE LAYING OUT AND CONSTRUCTION OF WORKS.

THE amount of money invested in water works in the United States at this time, 1907, is probably not less than $800,000,000, and the true value of the properties probably exceeds largely this figure. The amount of money spent on new construction, either in new projects, or in the development and enlargement of old ones, is certainly not less than $30,000,000 per year, and this amount is increasing.

Of this, one-half or less is for ordinary extensions of pipes, for installing meters, etc., and the rest is for new sources of supply, new pumps, and new purification works, and for the enlargement of old ones.

As a rule men do that best which they are accustomed to do, and that which they do frequently; they do less well or even badly the things that they have not done before. It looks easy enough to swim, or to fit a coat, or to play a piano; but we know that there is little prospect of success in doing these things in the first attempt of the novice.

It is much the same with cities in the building of water works. The work that is done frequently and regularly is done well, often extremely well; and that which is undertaken but seldom, or for the first time, is very apt

to be badly managed; and many misfit coats are worn with as good a grace as possible because the wearer does not wish to admit that he did not know how to cut his own coat. It may even be that he does not yet know it to be a misfit.

Most water works departments lay their own water pipes and services and set their own meters. That is to say, they do these things with their own men, and not by contract. As a rule the men employed are honest, intelligent and faithful. Practice of neighboring cities is studied and improvements are readily adopted. As a rule these men become skilfull as well as faithful, and their work is well done, and on the whole it is cheaply done.

The work done in this way represents at least a third of the whole construction account, and for it the departments usually secure full value for the money expended.

So far as they do not, it is mostly due to failure to provide and work to a sufficiently comprehensive general plan. A six-inch pipe is put down this year in a street where a ten-inch will be required five years hence; and when this happens the value of the six-inch first laid will have largely disappeared. Such losses can be almost entirely prevented by making a general plan of pipes suitable for the city after some years of growth, as nearly as that growth can be foreseen, and thereafter laying all pipe in accordance with it. Much money can be saved in that way in comparison with that which is spent under the too common system, or rather lack of system, where such pipes are put down each year as will relieve those

deficiencies of the system which then appear most pressing.

But the wastes from badly advised piping are trifling when compared to those on other parts of the construction work. This is because the departments are not used to laying out new works and building them. These things are required but seldom in any one city, and those having to do with one such installation are seldom on hand for the work of building the next one. If they were, their experience in many ways would have lost its value, owing to the progress of the art in the interval.

The study of recent works of neighboring cities is often relied upon, and if rightly used it is most helpful. But occasionally it is the reverse, where local conditions do not permit of copying. Storage reservoirs are built, where the need is rather for more catchment area tributary to the works; large distributing reservoirs are built, where smaller ones at higher levels, or more pumps or purification works would be far more useful; and types of construction useful in one place (or not, as the case may be) are cheerfully copied, where they are not suitable, and where the money could be better laid out in other constructions.

Certainly the sources of supply in America, taking it right through, cost a fourth more than they would cost if the methods of procedure that are well known and tried and adapted to the service were used in all cases.

Putting it in another way, the savings that could be reasonably made in water works construction by better management and by better engineering certainly amount to several millions of dollars per year in the United

States. And this does not include any allowance for savings to be made by new inventions and methods, which would largely add to this figure.

These possible savings represent a fund that may be divided between the people (in reduced water rates) and the engineers and superintendents and managers (in increased fees and salaries) who have the ability to bring the improvements about.

The public does, and always will, get most of the savings to be made in this way; but there is plenty of chance for men of ability and training to make great savings, and to receive generous compensation for doing it, and it is for the best interests of all that such services should be secured by the water departments and be adequately paid for by them.

Some cities and water companies have for many years made special efforts to secure such services, and the superior character of their works, and the increased values which they have obtained for their expenditures, are very clear to the few who take the trouble to inquire carefully into these matters.

On the other hand, some of our largest cities spend fifty per cent more on their works than is necessary, and sometimes even a hundred per cent more. Some do even worse than this. They build expensive works that on any rational theory of development they do not want, and cannot use to advantage.

Some of this is due to incompetent engineering advice. More of it is due to lack of advice or to failure to act upon it when it is obtained.

There is much more that might be written upon this

subject. It might be shown how in some lines of work the development is so rapid that even the most recent text-books are hopelessly out of date; how the subjects are becoming so complex that only the principles and not the important details can be treated in them; how the most efficient works are designed by groups of men, each attending to the parts which he best understands, and all under the general direction of a chief who has a clear idea of the end to be reached and the way of reaching it, though he may know less of many of the details than his subordinates; how the only way to learn a business is to be brought up in it, and how it cannot be learned by a casual inspection from the outside.

There is a strong temptation to develop some of these ideas, but it must not be done in this place. The writer is too directly interested in this business. To take up these matters would be too much like blowing his own horn, or at best, that of his profession. And besides, the water departments are steadily finding out the truth about these matters, and it is better that they should reach it in their own way.

At this point I wish to record a tribute to the many faithful, earnest, unpaid, or but slightly paid, men serving on water boards, and water committees, who have conscientiously studied the water problems of their cities and the best ways of solving them, and have stood for the right, even against strong but ignorant, or misinformed public opinion, and have in this way secured for the cities which they have served water supplies far better than would otherwise have been possible. I have known hundreds of these men, working year after year for the

good of their cities, entirely without compensation, and too often without thanks. Sometimes I have had an insight into what effort it has cost them. More often I have realized in some measure the value of their services to the communities in which they live.

It is this feature of our municipal life, too often forgotten or unknown, which must increase, as I believe it will, until it controls and excludes the baser elements. All honor to the men who quietly and without show do their full duty in the public service!

The water works superintendents also deserve a word, for they are among the hardest working and most poorly paid of men. With telephones in their residences they are on duty twenty four hours a day and seven days in the week. Vacations are few and short. All routine work usually goes through their hands, and very often, when they are stronger and better informed than their boards or committees, they practically determine the policy to be followed on all important matters. And, as a rule, the superintendents are right. As a rule they are not men of broad training, and often they miss the main chance, but on the whole, things are far more apt to go right when the superintendent's suggestions are followed, as they are pretty apt to be. Considering the conditions of service, it is surprising that the superintendents, as a class, are as efficient as they certainly are.

For the future it is to be hoped that the business will be made more of a profession; that the salaries paid will be larger; and that more men of broad technical training will be enlisted in the service.

CHAPTER XVIII.

ON THE FINANCIAL MANAGEMENT OF PUBLICLY OWNED WATER WORKS.

UNDER this heading I shall not attempt to describe the methods in actual use in American cities for financing their publicly owned water works. These methods are certainly varied and in many cases have admirable features. I propose here to bring together those methods and arrangements which seem particularly suitable, and then to make a financial scheme, ideal and visionary, to the extent that no city is following it throughout, but practical and tried, to the extent that most of its individual features are in successful use in one or another American city.

Likewise no treatment of the management of works by private companies is intended, though the plan outlined for city management follows closely, as it should, the arrangements that are suited to company management, with only one important point of difference: That is, that a company has properly for its end the payment of dividends, while the object of publicly owned works is to give as good service as possible, and to assess the cost of it as fairly as it can be done, both between the different takers at the present time, and between those of to-day and those of the years that are to come, during the period for which financial arrangements now made will be in operation.

The method to be here outlined is intended to secure this result as fairly as possible and with a minimum of trouble and inconvenience. It is more complicated than the methods now used by many water departments, but perhaps not more eleborate than is necessary to reach the desired results. For the methods of bookkeeping used by many water departments do not give a clear idea of their financial situation nor whether the present arrangements are leading to bankruptcy or to an unusually large surplus, unless the tendency is very strong.

This is often the case. Water departments collect more than is really needed, because of ignorance as to true conditions; but this tends to good service, and at worst only means that the present generation is paying the water bills of a future one in some measure. The opposite condition of too low collections is fortunately less common, though it has been followed by many cities. In the end it is far more disastrous to have the rates too low than too high.

In developing this proposed method a number of definitions will be necessary.

The True Value of a water works property as a whole is the fair market value of the property, including all real estate, rights of every kind, and structures, valued as if the present owners wished to sell, and as if a party at hand was desirous of buying and operating it. The case of the transfer of the works from private to public ownership may be assumed as the one for which there are most precedents, but transfer from one company to another, and from the city to a company may also be considered.

In general, it will be fair to assume that the franchise has expired and that no special allowance is to be made for it, though in some cases, as when a city has just condemned works with a valuable franchise for which it has paid, this would be unfair and the franchise value should be included. A going concern value, or a value for the fact of having actual connections and an established business, in comparison with a plant otherwise complete, but with a business yet to be acquired, may fairly be allowed.

The Appraised Value is an approximation to the true value, made at a given time by the water department, or for it, to be used as a basis of calculation. The methods of appraisal of water works properties need not be discussed here. Such properties are frequently valued by arbitration, or by court proceedings, for the purpose of fixing the sale value from a company to a city, or else for the purpose of serving as a basis for fixing the water rates which may be charged by a company. The principles of water works valuation have been ably discussed, and many lawyers and engineers have had extended experience in their application.

The Book Value or capital account is the value of the plant as a whole as used for the purpose of bookkeeping and computation. It may be arrived at in a number of ways, but most frequently by taking the book value of the preceding statement and adding to it all moneys spent since on construction, and substracting all allowances to be made for depreciation. The book value is to be kept as nearly as may be to the appraised value. This can be controlled by the amount marked off for depre-

ciation, and the depreciation should be adjusted to a simple schedule, to produce the required result as nearly as can be estimated. New appraisals may be made once in five or ten years, and the depreciation allowance increased or decreased as necessary to preserve an approximate equality.

The Bonded Indebtedness is the whole outstanding bonded obligation, less the sinking fund if there is one. Water works are generally paid for by cities in the first place by money raised on bond issues, and if the value equals the cost when first built, then the bonded indebtedness equals the value of the plant. But such a condition does not last. Usually with plants long in operation, and bonds partially paid off, the bonded indebtedness is far below the fair value of the property.

The City's Equity is the book value of the plant, less the bonded indebtedness. This corresponds to the stock value of a plant owned by a company. This equity I would treat exactly as if it were stock. Its ownership, vested in the city government as trustee for the citizens, gives the right to control the works, and a fair rate of dividends on its value should normally be earned by the operation of the plant.

The Construction Account must be rigidly separated from the operation account, and must show all money spent for new works and for additions.

The Operation Account must include all receipts and expenses in the normal operation of the works, including all interest payment on the bonds, and all other payments in the way of returns on the invested capital, and the allowance for depreciation.

The principal items that will go to make up the operation account are as follows:

Receipts: (1) the water receipts from all private consumers. This is the principal part of the income, and the methods of collecting it now in use are usually good and adequate.

(2) Receipts for water supplied to other city departments. The bills for such services should rest on meter measurement, should be made up at the same rates as would be charged to private takers for the same services, and should be promptly collected in all cases; and other city departments using water should be authorized and required to pay for it out of their appropriations, and when necessary those appropriations should be increased to cover this item. Only a few American cities have followed this practice. Most of them have supplied water without charge to other city departments. And the water departments have had to pay dearly for this generosity. For other city departments receiving water without cost and without limit are the most incorrigible wasters of water. The loss of water, which is equivalent to loss of revenue, and to increased operating expenses to keep up the supply, is a direct hardship on the water departments. Further, the loss is not limited to the direct loss. The example of public waste of water is irreconcilable with demands for private suppression of waste, and the public is not slow to see the point and act on it.

The only adequate way to stop this abuse is to meter the water to each department and collect for it at current rates from the appropriations for that department.

It need only be suggested that no successful commercial or manufacturing business is operated without making charges between different stores, factories and departments, and the necessity for such charges is certainly not less in city business.

(3) A collection from the city for hydrants and water for fire protection. Private water companies always charge for this service. Some publicly owned works also charge for it, but most of them do not. The charge should be made in all cases, but the rate of charge may be fixed at as low a figure as will cover the additional expense of maintaining hydrants, and the excess capacities of the pipes needed to make them effective. It is impossible to make a close computation of the fair charge for this service, but a reasonable approximation may be reached.

The rate of charge might appropriately be higher where a pressure sufficient to give fire streams direct from the hydrants is maintained, that is to say for hydrant pressures of seventy pounds and over; and lower where the pressure is so low as to be only effective when increased by the use of steam fire engines.

There will be some minor collections, but substantially these three items will make up the gross revenue, and the rates charged must be adjusted from time to time to produce the required income.

The payment side of the operating account will be made up principally of these five items:

(1) Operating expenses, including all salaries, general expenses, costs of pumping, protecting catchment areas, maintaining mains, services and meters, special engi-

neering and other professional advice, and, in short, all current expenses of every sort.

Space in city buildings not owned by the water department should be paid for at current rates for rent, and all services rendered by other city departments should be paid for, and the amounts included under this heading.

(2) Interest on all bonds outstanding. Usually there is no indebtedness outside of the bonds issued for construction, but if there is any other the interest payments upon it should be included in this item.

(3) Taxes on the works, assessed precisely as if the works belonged to a private company. Water works at present pay taxes on those parts of their works located outside the city limits to those towns, etc., in which they are located, but often under special rules of assessment made by the state legislatures, limiting the assessments to sums far below the full values of the properties. Holyoke has set the admirable example of taxing also the parts of the works in the city on the same basis as other property, and this example is worthy of being invariably followed. The basis of assessment should be as nearly as possible that followed on private property. There should be no attempt to unduly reduce the assessment. There is enough tax dodging, and the city which suffers from it should set a good example.

The reasons for leaving many forms of city property without taxation do not apply to water works property. It is commercial and profitable property, and is no less so because it belongs to the city, and it should be treated accordingly. School and university property is usually

exempt from taxation as long as used directly for educational purposes; but as soon as a revenue is derived from any part of it (even though that revenue is used for educational purposes) that part becomes taxable. This rule is just, and it should be applied to water works property.

(4) A group of charges, calculated on different theories, but all serving the same general purpose, including sinking fund payments, depreciation allowances marked off from the capital account and charged to the operating account at the end of the year, and all payments for renewals except minor renewals, paid out of operating expenses.

The amount to be paid into sinking funds is often established by law or by the provisions of the bonds; the amount paid for renewals is easily ascertained; but the amount allowed for depreciation is a far more difficult matter to arrive at. Its regulation ultimately depends upon the principle that it is to suffice to keep the book value and the true value as near together as possible, and time only will show whether the amounts assumed and used are adequate. In the meantime an approximation must be made and used, and modified whenever the experience already accumulated shows clearly that the charges that have been used are either too high or too low. At the outset it is better to allow too much for depreciation than too little.

When the whole cost of the works is represented by outstanding bonds, on which sinking fund payments are established, such payments alone may be sufficient or even excessive, and no further depreciation allowance need be made.

The allowance also may properly be less as more extensive and thorough renewals are made, thus keeping up the value of the property.

A general increase in the value of real estate and of the cost of building will make the works more valuable and reduce temporarily the need for a depreciation allowance, while the reverse condition will increase it. The allowance will also be less where the works are designed wisely with reference to future growth, so that but little will have to be discarded as the years go by, and as all parts of the plant are carefully looked after and protected. The care of the mains to prevent deterioration resulting from stray currents of electricity from trolley-cars (called electrolysis), for instance, would tend to reduce depreciation, and lack of attention to it might greatly increase it.

It is apparent that anything like a close computation is impossible. It is my feeling, based on the examination of a number of old works, and on estimates and computations relating thereto, that for most American water works an annual allowance of one per cent of the value of the property for all the charges coming under this item will suffice.

In some cases half this charge would no doubt suffice. With increasing values of real estate some works would stand no allowance at all for a time, but this should never be taken as a permanent basis. On the other hand, with badly designed works, or with sources of supply near the limit of their usefulness, either because of insufficient quantity or unsatisfactory quality, so that the early abandonment of parts of the works must be contemplated, charges of two or three per cent, or more,

might be required until a better and more permanent basis was reached.

(5) The payment of dividends on the stock, or on the city's equity in the property. The practical operation of the water works in New York, Philadelphia, Pittsburgh, and many other cities, results in the realization by the city of a certain return (and often a large one) on its investment in the works, but in no case is such a plan systematically and adequately carried out. In many cities the opposite principle is followed. The city's equity in the works is deliberately overlooked, and no payments are made on account of it.

The city's equity may be the result either of money raised by taxation and invested in the works, or of surplus profits from operation, which have been accumulated by the department. In the former case there can be no possible reason why the city should not receive a reasonable return on its investment. In the latter case it may be urged that as the accumulation is made up of water profits it should be used for the benefit of water takers; or, in other words, it is held that water should now be sold for less than actual cost because in the early years of operation it was sold for more than cost, and it is held that the accumulation from the profits of the early sales must be dispersed, and lost to the city.

The writer believes that it is fairer and more businesslike to regard the past as a closed chapter; to take matters as they stand; to find out the true cost of supplying water under present conditions as nearly as it can be ascertained, that cost including interest on all the money invested in or represented by the present value of the

plant, regardless of whether the equity now owned by the city has been produced by money raised by taxation or from surplus profits of the works themselves.

The management of the matter by the city may follow that which would be followed by an individual in managing a company for the benefit of the stock which he owned in it, with only this limit, that it may be supposed that the city only cares to make a moderate dividend rate, and will reduce the water rates whenever it can do so without reducing the dividend rate too low. In years of bad business it will reduce dividends or pass them. With good business, fair dividends will be paid, and the average dividend through a term of years may reasonably be kept somewhat greater than the rate of interest which is paid on the bonded indebtedness. The extra rate is to cover the element of risk in the business, and corresponds to the extra rate that there must be a chance of earning to make such a business attractive to a private investor.

As to the disposition of the dividends received by the city, the first use would be naturally to take up new stock to pay for additions to the works. It is clearly wise to do this, and the money so contributed for construction purposes would render unnecessary a corresponding amount of bonds. And this policy would increase the profits to the city from the business as its equity in the works increased.

In rapidly growing works, and where the city's equity at first was small, all dividends for many years could be wisely reinvested in the works; but ultimately a large net revenue to the city above the requirements for new

construction would result from this policy, and this revenue might be dedicated, if desired, to providing libraries and hospitals and parks, or any other public works not of a productive nature.

The general policy thus outlined, if adopted, would place publicly owned works on the basis of privately owned works in all respects but two; namely, the interest, apart from dividends, in giving the best possible service, and the absence of desire to earn more than a fair rate of interest on the capital invested. And these two reasons are precisely the reasons for public ownership, and they are substantially the only reasons for it. In all other respects the management should be the same in both cases. The publicly owned works should have the benefit of all the collections that a company could make in its place, and it should be subject to all the charges that a company would have to pay.

The comparison with a company is convenient and helpful, but the real reason for the adoption of these methods is not that they are used by companies, but because they are sound business, and would be equally desirable if there were not a water company in existence.

Their use will lead to the sale of water to everyone at actual cost, as nearly as that cost can be determined, and no one ought to expect to get water cheaper; and it will result ultimately in the ownership by our cities of splendid, safe, revenue-producing properties.

And the ownership of such properties will be doubly gratifying when they supply clean water.

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CHAPTER I

MATTER AND ENERGY

e of Physics.—As a result of the observations and ıde during many generations we are led to make certain · axioms which state that the physical universe has an ence, and that we are made acquainted with it solely by enses. If further we give the name *thing* to that with the ence of which we are acquainted by our senses, then it the physical universe there are only two classes of things; mes *Matter* and *Energy* are given. Time and space, and ır'ities, such as Number, Velocity, Position, Temperature, ıngs.

›ably be allowed at once that every form of matter, *i.e.* a of water, the air, &c., has objective existence; the most nent in favour of this belief being the fact that all experi- ›wn that under no circumstance whatever can we alter the ıtter. This result of experience, which is a fundamental all quantitative chemical experiments, is generally referred *rvation of Matter.*

ent that energy has an objective existence is, however, one › readily accepted: in fact, its acceptance by scientific men :k a comparatively short time. Experiments, with which later on, have, however, shown that energy, like matter, is and uncreatable by man. The objective existence is, as has pointed out, virtually admitted in a curious way by its ed for sale, it being quite common in manufacturing centres tice "Spare Power to Let." Again, water under a great ›plied for the purpose of working hydraulic lifts, &c., and :e paid for a given quantity of water is in these circum- higher than that for which the same quantity of water ined at such pressures as are found in the ordinary supply

BOOK I

MECHANICS AND PROPERTIES OF MATTER

PART I—INTRODUCTORY

CHAPTER I

MATTER AND ENERGY

1. Province of Physics.—As a result of the observations and experiments made during many generations we are led to make certain assumptions or axioms which state that the physical universe has an objective existence, and that we are made acquainted with it solely by means of our senses. If further we give the name *thing* to that with the objective existence of which we are acquainted by our senses, then it follows that in the physical universe there are only two classes of things; to these the names *Matter* and *Energy* are given. Time and space, and many other quantities, such as Number, Velocity, Position, Temperature, &c., are not things.

It will probably be allowed at once that every form of matter, *i.e.* a stone, a drop of water, the air, &c., has objective existence; the most powerful argument in favour of this belief being the fact that all experiments have shown that under no circumstance whatever can we alter the quantity of matter. This result of experience, which is a fundamental assumption in all quantitative chemical experiments, is generally referred to as the *Conservation of Matter*.

The statement that energy has an objective existence is, however, one which is not so readily accepted: in fact, its acceptance by scientific men only dates back a comparatively short time. Experiments, with which we shall deal later on, have, however, shown that energy, like matter, is indestructible and uncreatable by man. The objective existence is, as Professor Tait has pointed out, virtually admitted in a curious way by its being advertised for sale, it being quite common in manufacturing centres to see the notice "Spare Power to Let." Again, water under a great pressure is supplied for the purpose of working hydraulic lifts, &c., and since the price paid for a given quantity of water is in these circumstances much higher than that for which the same quantity of water would be obtained at such pressures as are found in the ordinary supply

mains, we infer that the purchaser thinks he is buying some "thing" besides the matter of which the water is composed.

From the foregoing considerations we are led to define Physics in its most general aspect as a discussion of the properties of matter and energy. It is, however, usual to restrict somewhat the definition so as to exclude the discussion of those properties of matter which depend simply on the nature of the different forms of matter (Chemistry), as also the properties of matter and energy as related to living things (Biology). The line of demarcation, however, between Physics and Chemistry has never been very clear, and of late years has practically vanished.

2. **Matter.**—Of the numerous definitions of matter which have from time to time been given, we may at present adopt the following: Matter is that which can occupy space.[1] This definition does not attempt to state what matter *is*, it only gives us a working definition, which in the present defective state of our knowledge as to the ultimate structure of matter is all that can be done.

We may speak of a limited portion of matter as a body, and of matter of a certain definite kind as a substance. Thus water, sugar, air, lead, are all matter, since they all occupy space or have dimensions. Since each of these things is a special kind of matter possessing distinct properties, they each form a distinct substance. A drop of water, a lump of sugar, the air enclosed in a given vessel, is each an example of a body.

3. **Energy.**—Energy may be defined as the capacity of doing work, where by work we mean the act of producing a change of the state of matter against a resistance which opposes any such change. The real meaning of this definition will be made clearer when we come to consider the various forms in which energy can exist.

4. **General Maxim of Physical Science.**—There is a maxim to the effect that the same cause will always produce the same effects, which is at the foundation of all our investigations in Physical Science. Since no event ever happens more than once, it is evident that the causes and effects spoken of above cannot be the same in all respects. What is meant is that if the causes only differ as regards the absolute time and place at which the event we are considering occurs, so the effects will also only differ as regards the absolute time and place. In order to meet this defect in the maxim, Maxwell has proposed to substitute the following: "The difference between one event and another does not depend on the mere difference of the times or the places at which they occur, but only on differences in the nature, configuration, or motion of the bodies concerned."

It follows that if a certain event has happened under a certain definite set of conditions, then if at any time exactly the same conditions again arise, a similar event must necessarily follow.

The belief in the truth of this maxim is at the foundation of all experiments, for an experiment is simply the artificial arrangement of certain causes, so that we may determine how, when one or more of the causes is inoperative, the event differs from that observed when all the causes ordinarily present are effective. If, then, by experiment we find that

[1] This definition, which is due to Descartes, is unsatisfactory, and a better definition will be given later when considering Newton's laws of motion.

ART VIII—ELECTROLYSIS, ELECTROMOTIVE FORCE OF CELLS, AND PASSAGE OF ELECTRICITY THROUGH GASES

CHAPTER XVI

ELECTROLYSIS

CHAPTER XVII

CONTACT E.M.F. AND THE VOLTAIC CELL

CHAPTER XVIII

ENERGETICS OF THE VOLTAIC CELL

CHAPTER XIX

PASSAGE OF ELECTRICITY THROUGH GASES—RADIO-ACTIVITY

PART IX—MAXWELL'S ELECTRO-MAGNETIC THEORY

CHAPTER XX

TRANSFERENCE OF ELECTRO-MAGNETIC ENERGY AND MAXWELL'S ELECTRO-MAGNETIC THEORY OF LIGHT

CHAPTER XXI

ELECTRICAL OSCILLATIONS

Those sections which may well be omitted on a first reading are marked with an asterisk.